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ABSTRACT

This is a two-part curriculum package for teaching the structure of atoms. The first part--the Teacher's Guide--contains information necessary for using the equipment in a typical classroom including learning goals, vocabulary, math skills, and sample data for each activity. The second part of the package consists of photocopy masters for a set of student activity guides, a cut-and-paste quiz builder, and scoring rubrics for assessment of those activities. The photocopy masters are designed for copy and use in the classroom. Most experiments have three skill levels to accommodate students from a wide range of grades and abilities. Level A activities lead students through a basic understanding of atomic structure and atomic bonding. Students learn about the role of atoms as nature's building blocks. In Level B, the same concepts are introduced as in Level A but at an accelerated pace and in greater depth. Both levels use the Atom Building Game to reinforce concepts through visualization and manipulation. Level C builds on concepts introduced in Level B, with atomic and nuclear applications: atomic spectra and nuclear decay. The Activity Guides are written to provide a framework for encouraging students to observe and learn science process skills as well as content. (PVD)

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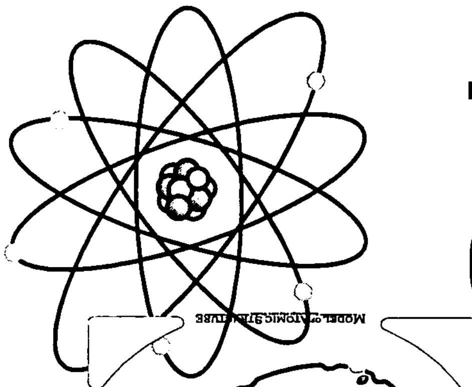
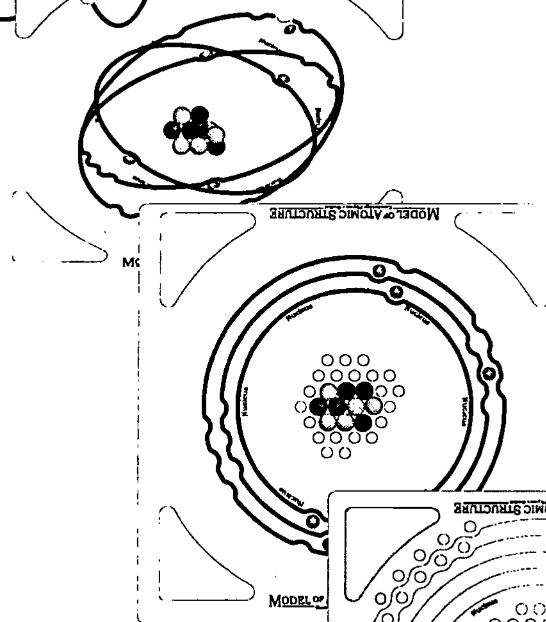
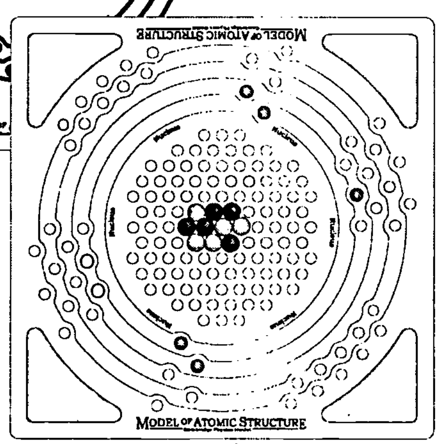


The Structure of the Atom





Teacher's Guide
Levels A,B and C

SE060709

PRELIMINARY LIMITED EDITION

The CPO Curriculum Package

This curriculum package has two parts. The first part is the **Teacher's Guide**, which includes information necessary for using the equipment in a typical classroom. The second part of the package consists of a photocopy masters for a set of **Student Activity Guides**, a cut and paste **Quiz Builder**, and **Scoring Rubrics** for assessment of the Activities. These photocopy masters are designed to be copied and used in the classroom.

Most of the experiments have three skill levels to accommodate students from a wide range of grades and abilities.

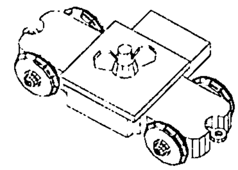
Teacher's Guides

- An elementary review of key concepts to be used in the experiment
- Experimental techniques, measuring tips, and equipment maintenance
- Learning goals for each level
- Vocabulary for each level
- Math skills checklists for each level
- In-depth reference, with a review of mathematical techniques and derivations
- Detailed discussion of answers and lab results for each Activity Guide
- Detailed discussion of Assessment questions and derivations of answers

Photocopy Masters

- Classroom ready Activity Guide worksheets
- Self guiding illustrated set up and procedure for hands-on activities
- Includes writing space, discussion questions, graph paper, and data tables
- Activity Guides can be collected for portfolio/performance assessment
- Customizable cut and paste Quiz Builder
- Scoring Rubrics for weighted assessment of each Activity

Level A
Suggested Curriculum Sequence



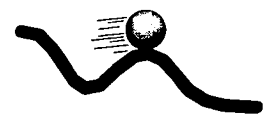
Motion
Speed
Acceleration

1

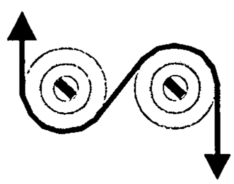
CAR AND RAMP

2

Energy
Speed
Graphing



ROLLERCOASTER



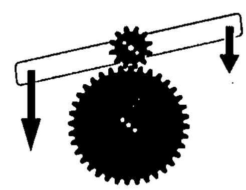
Simple Machines
Force
Work
Energy

3

ROPES AND PULLEYS

4

Simple Machines
Angles
Rotation
Work



GEARS AND LEVERS

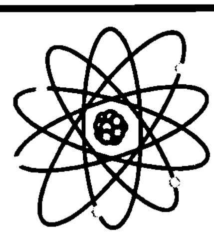
5

Harmonic Motion
Time, Frequency, and Period

PENDULUM

6 Sound and Music

SOUND AND WAVES



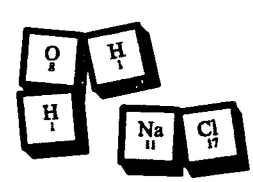
Atomic Structure
Electrons, Protons,
and Neutrons

7

ATOMIC BUILDING GAME

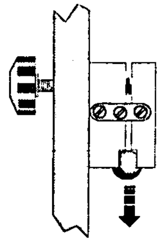
8

The Elements
Chemical Equations



PERIODIC PUZZLE

Level B
Suggested Curriculum Sequence



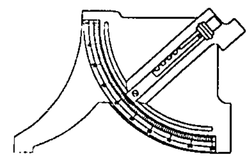
GRAVITY DROP

1

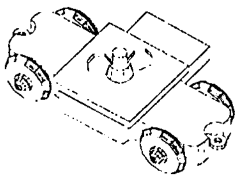
Motion in a Line
Speed and Acceleration
Graphing

2

Vectors and Trigonometry
Motion in a Plane



MARBLE LAUNCHER



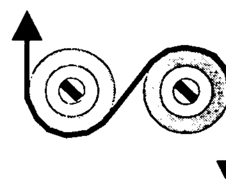
CAR AND RAMP

3

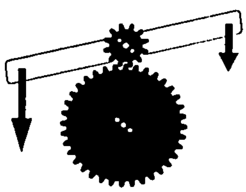
Force and Newton's Laws
Uniform Acceleration
Multiple Variables

4

Simple Machines
Work and Energy



ROPES AND PULLEYS



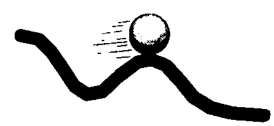
GEARS AND LEVERS

5

Circular Motion
Rotating Machines
Angles, Degrees, and Radians
Torque

6

Conservation of Energy



ROLLERCOASTER

PENDULUM

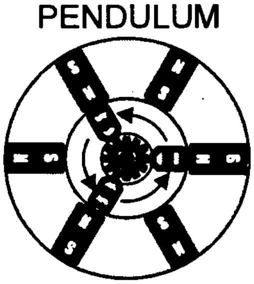
7

Harmonic Motion
Time, Frequency, and Period

8

Sound and Music
Frequency and Wavelength

SOUND AND WAVES



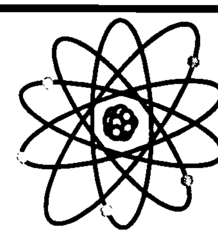
ELECTRIC MOTOR

9

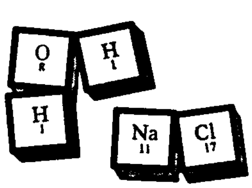
Electricity and Magnetism

10

Atomic Structure,
Bonding and Valence,
Atoms, Ions, and Isotopes



ATOM BUILDING GAME

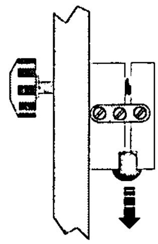


PERIODIC PUZZLE

11

The Elements
Chemical Equations

Level C
Suggested Curriculum Sequence



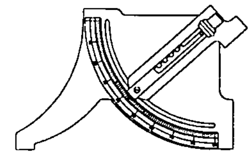
GRAVITY DROP

1

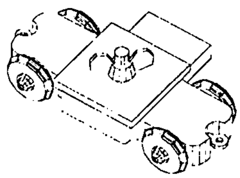
The Acceleration of Gravity
Uniform Accelerated Motion in One Dimension

2

Vectors and Trigonometry
Accelerated Motion in a Plane



MARBLE LAUNCHER



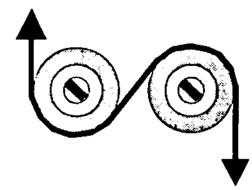
CAR AND RAMP

3

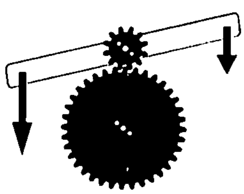
Force and Newton's Laws
Friction
The Physics of the Inclined Plane

4

Simple Machines
Work and Energy



ROPES AND PULLEYS



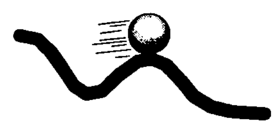
GEARS AND LEVERS

5

Circular Motion
Rotating Machines
Angles, Degrees, and Radians
Torque

6

Kinetic and Potential Energy
Conservation of Energy
Rotation



ROLLERCOASTER

PENDULUM

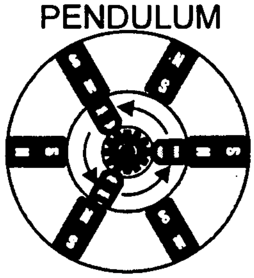
7

Harmonic Motion
Time, Frequency, and Period

8

Harmonic Motion
Resonance
Frequency and Wavelength
Interference

SOUND AND WAVES



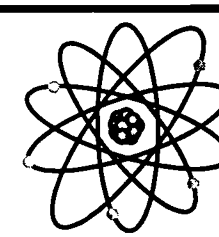
ELECTRIC MOTOR

9

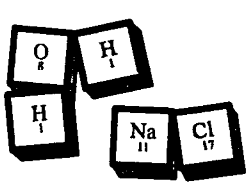
Simple Electric Circuits
Magnetism
Work and Energy

10

Valence and Bonding
Atoms, Ions, and Isotopes
Atomic Spectra and Lasers
Radioactive Decay



ATOM BUILDING GAME



PERIODIC PUZZLE

11

Valence
Chemical Equations

Organization of the Teacher's Guide

The **Reference** chapter provides a deeper level of background, especially the mathematical tools used in the activities.

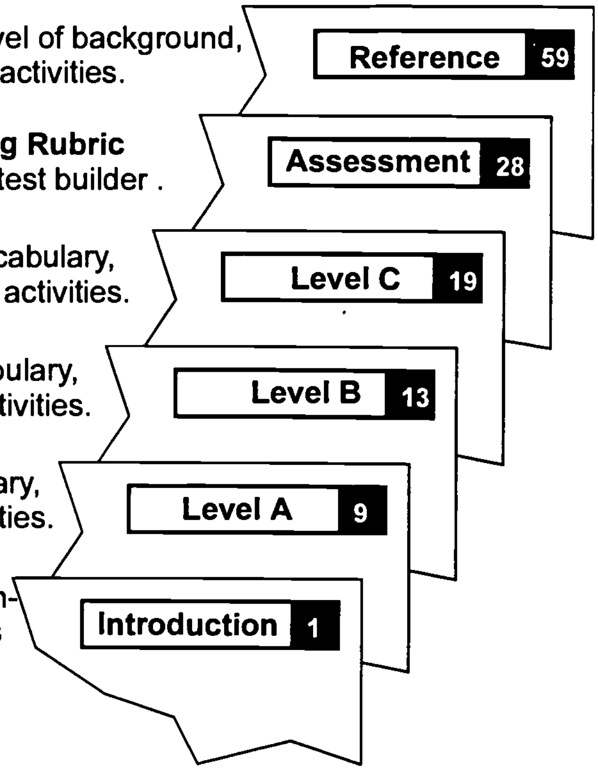
The **Assessment Package,** together with the **Scoring Rubric** and **Quiz Builder Masters,** provides a customizable test builder .

The **Level C** chapter presents Learning Goals, Vocabulary, Math Skills, answers, and sample data for Level C activities.

The **Level B** chapter presents Learning Goals, Vocabulary, Math Skills, answers, and sample data for Level B activities.

The **Level A** chapter presents Learning Goals, Vocabulary, Math Skills, answers, and sample data for Level A activities.

The **Introduction** chapter gives a review of the key concepts used in the experiment, and detailed descriptions of the set up, use, and maintenance of the equipment.



Organization of the Photocopy Masters

Photocopy Masters of **Activity Guides, Scoring Rubrics**, and **Quiz Builders** are included at the end of the Teacher's Guide. The sections are identified by the legend in the page footer. Activity guides are further identified by the square icon in the upper right corner.

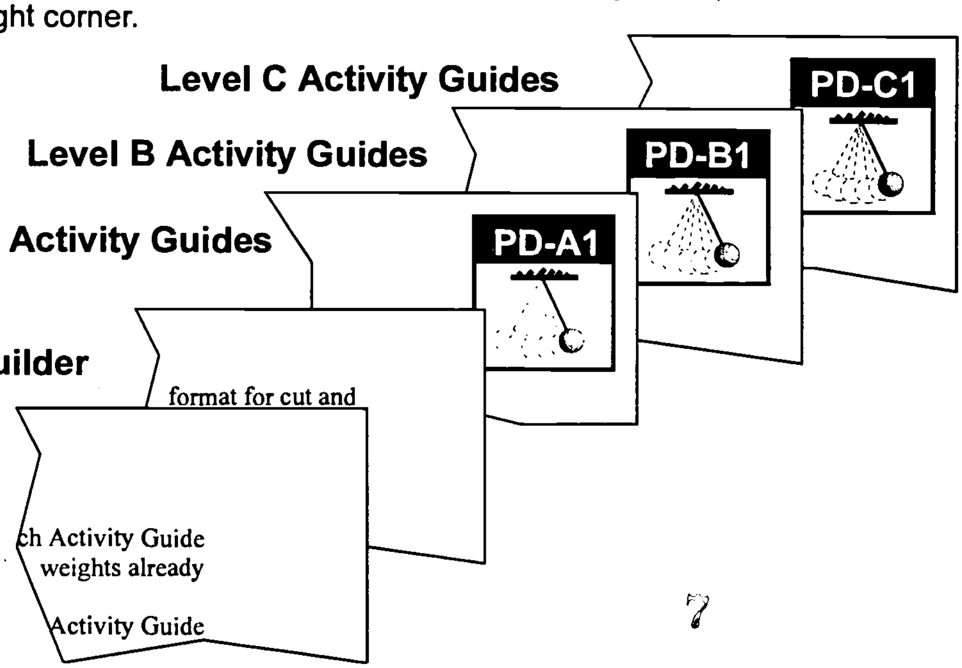
Level C Activity Guides

Level B Activity Guides

Level A Activity Guides

Quiz Builder

Scoring Rubrics



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Student Activity Guides

The **Activity Guides** are comparable to classroom lab procedures and are meant to provide a structure for guiding the students' exploration through a particular experiment. Activity Guides are provided at up to **three skill levels** which differ in both language and content. The table below provides an overview of the three levels and the approximate grade range for which each is intended. Please note that the grade ranges are only approximate. Which level you use is dependent on the skill set and motivation of your students.

Level A **Introductory level for late elementary or middle school** ***(Grades 5-9)***	• Learn to be comfortable with numbers and measurements, and analytical thinking • Practice using simple mathematical tools, such as multiplication, division, and ratios without formal mathematical language (i.e. no equations) • Explore key concepts such as speed, force, and work • Develop qualitative understanding of concepts through observation of patterns in measurements
Level B **Advanced middle school, introductory high school level** ***(Grades 8-12)***	• Use measurements to discover quantitative rules of nature • Extend mathematical tools to introductory algebra, simple geometry, functions such as square roots, discussion of errors, and more complex graphing skills • Develop inquiry based scientific method, including quantitative testing of theory against measurement
Level C **High school physics, basic (non-calculus) college physics.** ***(Grades 10-College)***	• Emphasis on rigorous deduction of physical laws through experimental and theoretical analysis • Emphasis on problem solving and extending concepts learned to complex experimental situations • Mathematical tools include trigonometry, algebra, geometry, and ideas from calculus (although no calculus)

Using the Three Levels

The three level curriculum can be effectively used in many different ways. Science and math learning can be **vertically integrated** with common basic equipment. The same student may see the Atom Building Game in middle school at Level A, and again in high school at Level B or C. As the student's skills grow, the same familiar equipment can be used to reach deeper comprehension. This process is akin to a child using a crayon to learn to draw and an adult artist using the same crayon in a much more sophisticated manner.

Multiple level learning works between grades, but also within a single grade/classroom. The graduated skill levels encourage quicker learners to move on to more advanced exploration. Slower learners can succeed at basic levels, with each group working at a challenging but comfortable pace. With today's heterogeneous school population the ability for **groups** to **progress independently** is crucial to providing an exciting and fulfilling learning environment.

The Level A activities are complete in that they cover the chosen topics with the Level. The Activities were designed to meet national and state frameworks for math and science for the later elementary and middle school grades. *Students may need calculators.*

Level B was designed for the advanced middle school class or introductory high school course. Level C is appropriate for high school physics or elementary college work. **The B and C Levels are not independent, but together form a consistent progression from basic observation to complex analysis.** In many cases the Level C activity assumes that Level B has been completed by the student. Students with high aptitude in math and science may progress from Level B to Level C within the same class without repeating the same material twice.

The Activity Guides are written to provide a framework for encouraging students to observe and learn process skills as well as content. We expect (and hope) that your classroom activities will go beyond our programmed Guides. The Activity Guides should be considered a foundation on which your students will erect a house of understanding. The house will be shaped differently for each student. Some will be grandly constructed with much detail, and others will be simple. In all cases, however, the student's exploration should not be stopped at the foundation. If you develop a novel way to use the materials, please let us know; we can then share your discovery with other teachers.

Using the Atom Building Game Activities

The heart of the Atomic Structure Curriculum package is the set of **Activity Guides**. The photocopy masters of these activities are at the end of this package, and should be copied and distributed (one per student) to accompany the hands-on activity. Chapters 2, 3, and 4 of this package comprise the **Teachers Guides** for the level A, B, and C activities. The Teacher's Guide presents the learning goals, vocabulary, math skills, and sample data for each activity, as well as some sample answers (and errors) for the activity questions. The content of each activity is summarized below:

Activity A1: Building Atoms: What are nature's building blocks?

In this activity, students explore the rules for electromagnetic forces that attract and repel charges. They learn that atoms consist of a nucleus with protons and neutrons, and electrons in an outer shell. The Atom Building Game board serves as a visual and manipulative reinforcement of the rules for the construction of atoms.

Activity A2: Building Molecules: Putting together nature's building blocks.

In the second Activity, the students continue manipulating the Atom Building Game board. We now study the layers of electrons around the nucleus of the atom. These layers have patterns, and we learn that atoms prefer certain arrangements of electrons within these layers. From this, it is an easy jump to bonding, and the combination of atoms into molecules in such a way that the atoms are in a more preferred state than if alone. We end by combining three Atom Building Game boards to build a water molecule.

Game G1: Atomic Challenge: A game of nuclear reactions

In this activity, we play a game which reinforces the rules of atomic structure. The rules of the game are constructed to make the game fun, while at the same time intuitively building the picture of the atom and the forces which hold it together. This game can be played by Level A, Level B, or Level C students. In any case, it should be played after completing the appropriate regular activities.

Game G2: Photons and Lasers: A stimulating game of laser excitement

In this activity, we play another game which reinforces the rules governing the behavior of electrons in the shell of the atom. The students will note that, for all the activity, there is no action involving the nucleus -- an important concept in understanding the difference between atomic physics (chemistry) and nuclear physics. Again, the rules of the game are constructed to make the game fun and intuitively build the students' physical intuition. The game can be played by Level A, Level B, or Level C students. In any case, it should be played after completing the appropriate regular activities.

Activity B1: Forces in the Atom

In this activity, students explore the rules for electromagnetic forces that attract and repel charges. They learn that atoms consist of a nucleus with protons and neutrons, and electrons in an outer shell. The concept of the strong nuclear force (which holds the nucleus together) is introduced, and compared to the electromagnetic force (which holds electrons to the atom). The Atom Building Game board serves as a visual and manipulative reinforcement of the rules for the construction of atoms.

Activity B2: Atoms, Isotopes, and Ions

This is a continuation of Activity **B1.** Several important vocabulary items are introduced, as are the names for the elements.

Activity B3: Valence, Chemistry, and the Periodic Table

In this Activity, the students continue manipulating the Atom Building Game board. We now study the layers of electrons around the nucleus of the atom. We examine ionization potentials and the partial filling of electron shells, and look for patterns in the sequence of elements. The Periodic Table is introduced, and similar patterns to chemical properties are discussed. From this, it is an easy jump to bonding, and the combination of atoms into molecules in such a way that the atoms are in a more preferred state than if alone. We end by combining two Atom Building Game boards to build a salt molecule.

Contents

Chapter 1 Introduction

Section 1.1: What are Atoms?

Atoms are the building blocks of matter. By understanding how atoms are constructed and how they interact, we can understand a great deal about the materials which make up our world.

Atoms are the building blocks of all of matter. Everything that we see, hear, feel, smell, and touch is composed of atoms. Yet an individual atom is so small that it takes *millions of millions of millions* of them to make up your fingernails or to form the sound you hear when a pin drops. Physical and chemical processes that take place on our planet, either naturally or by human intervention, can be understood by understanding the nature of the atom, and how different atoms interact to make up the world in which we live.

Although we will find that atoms are divisible into smaller particles, the atom is important because it is the smallest piece of matter we can divide without losing the chemical properties of the matter. For example, we may divide the graphite from the ashes in a barbecue into smaller and smaller pieces, until we eventually have only single carbon atoms. These atoms still have all the properties of carbon, and are distinct from other types of atoms. If we break the atoms apart further, we lose the chemical properties of carbon, and the pieces are indistinguishable from the particles we would get by smashing any other material.

Atom

The basic building block of matter, and the smallest unit of an element that retains the properties of the element.

Understanding the atom is one of the most powerful tools in the understanding of chemistry. The Atom Building Game and Periodic Puzzle provide a series of hands-on activities which develop basic concepts in an intuitive way which most students find accessible.

The concept of the atom is a difficult one to grasp, simply because we are unable to resolve the world into individual atoms in our daily lives. Unless you work in a specialized laboratory, you will never see, touch or feel individual atoms. Understanding the structure of the atom can be very difficult, because there are no simple experiments that can be performed that make it clear what atoms look like and how they behave. The role of the Atom Building Game is to present results from experiments performed nearly a century ago, and then to challenge the students into understanding how those rules work. Once that understanding is developed, many practical applications of those results can be investigated.

The atom itself is made of a nucleus and electrons. The nucleus is at the center of the atom, and it has a positive electrical charge. Electrons, which have negative electrical charge, live in shells which surround the nucleus. The nucleus is made up of protons and neutrons.

Electron

The negatively charged particles which form the outer shell of the atom.

Proton

The positively charged particles which reside in the core of the atom.

Neutron

The uncharged particles which reside in the core of the atom.

The mass of an atom is due primarily to the mass of the nucleus - the mass of a single electron is almost 2,000 times less than the mass of a single proton or a single neutron. However, the nucleus occupies less than 1% of the total volume of the atom. Most of the atom is actually empty space: if the atom was the size of your classroom, then the nucleus would be the size of a grain of sand in the center of the room.

Nucleus

The core of the atom, which is made up of protons and neutrons. The nucleus accounts for nearly all of the mass of the atom, but only a tiny fraction of its volume.

Although most atoms are neutral (meaning they have no electrical charge), some of the constituents of the atom do have charge, namely the proton and the electron. Each proton has a charge of +1 units, and the each electron has a charge of -1 units. Neutrons have no charge.

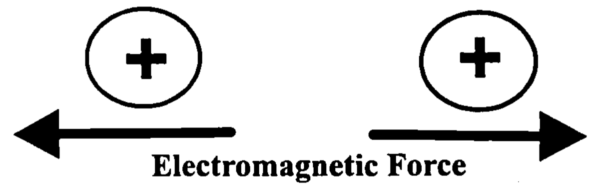


Figure 1.1: The electromagnetic force is attractive for unlike charges, and repulsive for like charges.

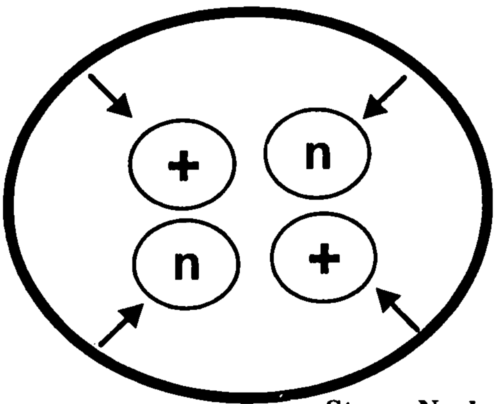
Section 1.2: What Holds an Atom Together?

The atom is held together by two fundamental forces of nature: the electromagnetic force and the strong nuclear force.

The atom is held together by two fundamental forces which exist in the universe: the electromagnetic force and the strong nuclear force. The electromagnetic force is one that we encounter in everyday experiences. For example, the attraction between the north and south poles of a bar magnet is due to the electromagnetic force. Electrical charges behave similarly, due to the same force: like charges repel and unlike charges attract, as in Figure 1.1. The electromagnetic force is responsible for keeping the electrons attached to the nucleus in an atom. Since the nucleus is made of protons and neutrons, it is positively charged, while the surrounding electrons are negatively charged. We have all heard the phrase "opposites attract": since the nucleus and electrons have opposite charges, they attract. It is this attraction which binds the atom together.

The strong nuclear force is one that we do not encounter in daily lives, and is somewhat more abstract. A logical question is: "If we cannot make tangible observations of this force, then how do we know it exists?" Actually, it comes about from thinking about the nature of the electromagnetic force.

The electromagnetic force is responsible for opposite charges attracting, such as occurs between the positively-charged nucleus and the negatively charged electrons in an atom. However, the electromagnetic force would then also be responsible for like charges repelling one another. The question then arises: how do multiple protons live together in the nucleus? For example, helium, which we use to fill balloons to make them lighter than air, is an element with two protons in the nucleus. If only the electromagnetic force existed, then we could argue that helium could not exist, because the protons in the nucleus would repel each other and the nucleus would fly apart. However, since we know that helium does exist, we know that there must be another force which makes the nucleus stable. This force is the strong nuclear force, (see Figure 1.2).



Strong Nuclear Force

Figure 1.2: *The strong nuclear force is the glue that holds the nucleus together. Since it is much stronger than the electromagnetic force, it can overcome the repulsion of the positive charges in the nucleus.*

The strong force is an attractive force between protons, but also causes and attraction between neutrons and between protons and neutrons. From common experiences we know that like charges repel, so it makes sense that the strong nuclear force only acts over distances that are smaller than we are used to dealing with. In fact, the strong nuclear force acts only over distances which are comparable to the size of a nucleus.

Section 1.3: Why Learn About Atoms?

All the materials that make up our world are made up of atoms. By understanding how atoms bind to similar or dissimilar atoms, we can understand how some materials can be made strong, or hard, or smooth, or heat-resistant.

To understand the physical and chemical properties of any material on Earth, first we must understand the fundamentals of that material: its atomic structure. The atomic structure of a material can give us information about how well it can perform the task we are asking of it. For example, if we want to determine whether or not a certain material can be used to build a bridge, we need to know whether it can hold up under the stresses and strains that materials on a bridge will face. Knowing the atomic structure of the material and how millions of atoms combine to form the material can give us this information.

With the Atom Building Game, we are focusing on how the chemical properties of materials are determined by atomic structure. Understanding chemistry is important for many reasons. The chemistry of materials is used in many practical applications, such as synthesizing new drugs for curing diseases, converting coal and natural gases into useful electrical energy, and for studying the environmental changes on our planet.

Chemical properties of materials are determined by their atomic structure. If we understand how atoms are "built up", then we can use that information to determine how atoms will combine with one another to form the

materials that we are interested in. In the Atom Building Game, we proceed step-by-step in the building of an atom.

Section 1.4: The Atomic Structure Curriculum

In Level A, we introduce the most basic concepts of atomic structure:

- Like charges repel,
- Opposite charges attract,
- The atom is made up a nucleus and electrons,
- The nucleus is positive, electrons are negative,
- Electrons don't live in the nucleus, they live in levels surrounding the nucleus,
- Ions are atoms that have had some of their electrons stripped away,
- Atoms want to be neutral, but they also want to have full electron levels (this is how we explain bonding: atoms cooperate by sharing electrons, so that each atom has full electron levels).

We use the Atom Building Game throughout these lessons to visually reinforce these concepts. Different activities are structured with rules contrived to reinforce these concepts through fun manipulatives.

We conclude Level A by building a molecule that every child has heard of: H_2O, better known as water.

In Level B, we reintroduce the same concepts as Level A, but at an accelerated pace and in greater depth. We go beyond the topics in Level A, as well as start to introduce common terminology. Elements are determined by the atomic number (the number of protons in the nucleus). Isotopes are determined by the mass number (the number of protons plus the number of neutrons in the nucleus). Chemical properties of elements are determined by the valence (the number of electrons in the outermost electron level).

We introduce valence and the idea that atoms "prefer" a full valence by pointing out trends in how the first ionization energy varies for different elements.

These activities also use the Atom Building Game in a variety of activities designed to reinforce the concepts through visualization and manipulation. Again, we conclude our lessons with bonding. In Level B we finish by describing ionic bonding, and build the most familiar ionic compound: NaCl, better known as table salt.

Level C builds on the concepts introduced in Level B, with atomic and nuclear applications: atomic spectra and nuclear decay. There are energies associated with the electron levels surrounding the nucleus. The Atom Building game allows students to visualize the electronic levels easily. On the board, levels closer to the nucleus have lower energy, as they do in real atoms. Atoms can be in the ground state (when all the electrons are in their lowest energy levels), or they can be in an excited state. When atoms make transitions from excited states to

states with lower energy, they emit photons. The study of these photons is called spectroscopy. Lasers work because of the photons emitted when excited atoms de-excite to the ground state.

The Atom Building game makes it easy to introduce the concepts of nuclear stability and radioactive decay. When a radioactive isotope decays, it emits a particle. Students can "transmute" the nucleus to determine what the decay product will be.

Level C concludes with the idea that as atoms are "built up" by adding protons to the nucleus, electrons fill the levels in a specific order. Spectroscopic notation for the orbitals is introduced; the Atom Building board already divides the electron levels into the correct number and type of orbitals. Orbitals fill up in a special order. (The order is presented without in-depth explanation since a proper explanation requires quantum mechanics, which is beyond the Atom Building game.)

Chapter 2
Level A Activities

Section 2.1: Learning Goals for Level A

The Atomic Structure Curriculum provides a basic introduction to atoms. We introduce the key concepts:

- Like charges repel and opposite charges attract,
- The atom is made up of a nucleus and electrons,
- The nucleus is positive and electrons are negative,
- Electrons don't live in the nucleus, they live in shells around the nucleus,
- Electrons prefer to fill up the lower shells first,
- Ions are atoms that have had some of their electrons stripped away,
- Atoms want to be neutral, but they also want to have full electron levels.

We use the Atom Building Game board as an atomic model for these activities. The board reinforces the rules of atomic structure visually, and the activities reinforce the rules by manipulative activities. The activities lead the students through a basic understanding of atomic structure and atomic bonding.

The lesson finishes with the construction of a water molecule using three boards (a larger group activity).

Apparatus:

- One Atom Building Game board per group, including one bag each of electrons, protons, and neutrons per group.
- Three Groups must combine boards for the last activity of **A2.**
- One Activity Guide per student

Key Vocabulary for Level A

- **Atom:** Atoms are the building blocks of matter. An atom is a nucleus surrounded by electrons, usually with the number of electrons equal to the number of protons in the nucleus.
- **Nucleus:** The core of the atom. The nucleus is made of protons, which are positively charged, and neutrons, which have no charge. The nucleus is positively charged. The number of protons in the nucleus determines what the atom is (i.e. what element: Hydrogen, Oxygen, etc.).
- **Electrons:** Electrons are elementary particles. They are negatively charged (charge of -1 per electron). They can be free particles, or they can be bound to a nucleus. When electrons are bound to a nucleus, they can live only in specific levels, which are determined by the positive charge of the nucleus and the number of other electrons already bound to the nucleus.
- **Protons:** Protons are postitively charged particles (charge of +1 per proton). Protons and neutrons form the nucleus. Protons are far more massive than electrons (about 2000 times more massive).
- **Neutrons:** Neutrons are neutrally charged particles. Protons and neutrons form the nucleus. Neutrons have about the same mass as protons (i.e. about 2000 times the mass of electrons).
- **Charge:** A basic property of nuclear physics. Electrons have -1 charge unit each, protons have +1 charge unit each, and neutrons have 0 charge unit each. Any two particles with the same nonzero charge repel each other, and any two particles with opposite charges attract each other. Every nucleus is positively charged. It is the positive charge of the nucleus that attracts electrons to it to make ions or atoms.
- **Ion:** An ion is an atom with a different number of electrons than protons. Since the electron and protron charges don't balance out, the ion has net charge. If an ion has the same number of electrons as protons in the nucleus, it is neutral, and we say it is an atom, not an ion. If an ion has fewer electrons in the shell than protons in the nucleus, the ion is positively charged. If an ion has more electrons in the shell than protons in the nucleus, the ion is negatively charged.

- **Ionize:** To take away electrons from or add electrons to an atom. This turns a neutral atom into a charged ion. When all the electrons have been stripped from an atom, the atom has been "fully ionized."
- **Bond, bonding:** Two or more atoms can share electrons so that for each of them, the last electron level appears to be full. When atoms "cooperate" in such a manner, they form a bond. When two or more atoms form a bond, they stick together to form a cluster, which we call a molecule. Bonding is the process of forming a bond.
- **Molecule:** The cluster of atoms which forms when they bond. Two very common molecules are $NaCl$ and H_2O. $NaCl$ is the chemical name for table salt, a molecule formed when one sodium (Na) atom bonds with one chlorine (Cl) atom. H_2O is the chemical name for water, a molecule which forms when two hydrogen (H) atoms bond with one oxygen (O) atom.

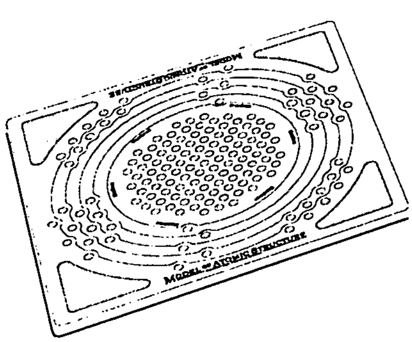
Section 2.2: Building Atoms

Activity Guide AB-A1

The first Activity Guide concentrates on the internal structure of the atom. The students should learn where in the atom the electrons, neutrons, and protons reside, and how the electrical charge is determined. A few simple atoms will be built on the Atom Building Game board for visualization.

Everything is made of atoms. Atoms are the building blocks of nature.

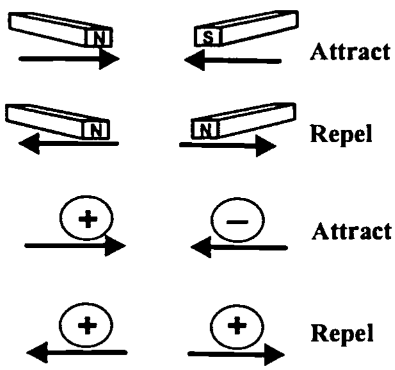
The ancient Greeks once thought that atoms were the smallest pieces of matter; that they were indivisible. We now know that even atoms are made up of smaller pieces. In these activities, we will learn how to build atoms from these pieces.



Atoms are incredibly tiny, far too small for us to do simple experiments on them. Instead of building real atoms, we will use our model of the atom. You should have one Atom Model per group, along with three bags of marbles (red protons, blue neutrons, and yellow electrons). The rules for the activities below are the same rules that nature follows in building atoms -- but we will be able to see what we are doing by using the model.

Open up the bags of marbles, and put a few of each type in the corner pockets of the Atom Model.

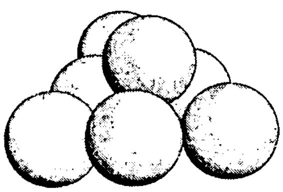
ELECTRIC FORCES



Have you ever experimented with magnets? Electric charges obey similar rules to magnets. If you remember, magnets attract North to South and South to North, but repel North to North and South to South. Electric charges are labeled plus or minus (positive or negative) instead of North and South.

Electric charges obey these rules:

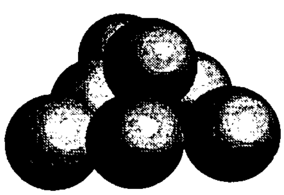
- positive charges repel other positive charges
- negative charges repel other negative charges
- positive charges attract negative charges



Protons (red marbles) have positive electric charge

A1.1: Take two protons (red marbles) in your hands. According to the rules of electric forces, should you feel a force? If so, do the protons repel or attract each other?

repel, since they are like charges



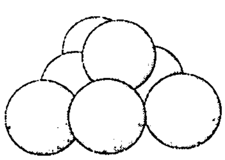
Neutrons (blue marbles) have no electric charge

A1.2: Now take two electrons (yellow marbles) in your hands. Do they repel or attract one another?

repel, since they are like charges

A1.3: Now take two neutrons (blue marbles). Do they repel or attract?

neither, since neutrons are uncharged



Electrons (yellow marbles) have negative electric charge

A1.4: How about a proton (red marble) and a neutron (blue marble). Do they repel or attract?

neither, since the neutron is uncharged

A1.5: How about a neutron and an electron?

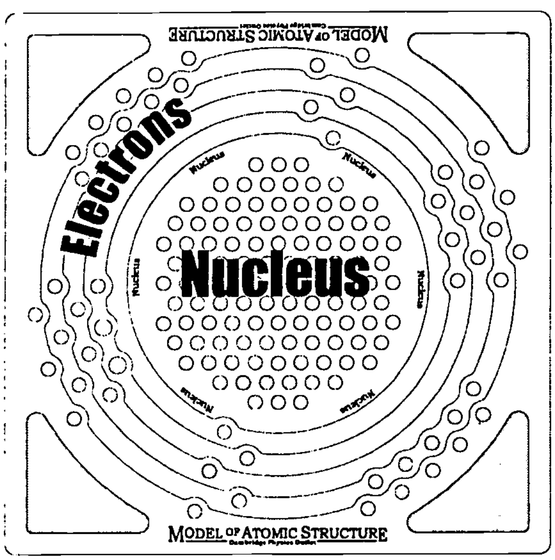
neither, since the neutron is uncharged

A1.6: How about a proton and an electron?

attract, since they have opposite charges

A1.7: If the electron is attracted to the proton, is the proton also attracted to the electron?

yes



Atoms have a nucleus and electrons. Only protons and neutrons live in the nucleus. On the board, this means that only red marbles (protons) and blue marbles (neutrons) go in the center.

A1.8: Can electrons live in the nucleus?

No

A1.9: Is the nucleus positively charged or negatively charged?

Positively charged

Nucleus - the core of the atom, containing protons and neutrons

START BUILDING AN ATOM:

Make a nucleus that has three protons in it on the model. Make sure that the marbles go into holes on the model.

A1.10: What is the charge of this nucleus?

The charge is +3, since each proton has a charge of +1

A1.11: Add three electrons to the model (where do they go?). What is the charge of the atom now?

The electrons go in the shell (not the nucleus). The charge is now zero (neutral).

A1.12: Now take away one of the electrons. What is the charge of the atom now?

There are three protons and two electrons, so the net charge is +1.

ADD NEUTRONS TO THE ATOM:

Atoms usually have about the same number of neutrons as protons in the nucleus. Sometimes they have a few more neutrons, sometimes the same number, rarely less.

Continue building your atom with three protons and three electrons.

A1.13: How many neutrons are probably in this atom? Add them.

There are probably three. Four is also acceptable.

A1.14: What is the charge of the atom now?

It is unchanged. Neutrons have no charge, so the net charge is still zero.

A1.15: Add another neutron. What is the charge of the atom now?

It is still unchanged. (Zero).

WHERE DO THE ELECTRONS GO?

You know that the nucleus is positive and that electrons are negative. This means that the electrons and the nucleus are attracted to each other. This is how an atom is held together.

Electrons cannot live in the nucleus. Let's figure out where the electrons prefer to go.

Start with your neutral atom of three protons, three neutrons, and three electrons.

A1.16: If the lower levels for the electrons are closer to the nucleus, where do you think the electrons should go? Why?.

They want to get as close to the nucleus as possible, since that is what attracts them.
Since they cannot go into the nucleus, they will fill the lowest possible levels. Two of
them should fill the lowest level, and the third will lie somewhere on the second level.

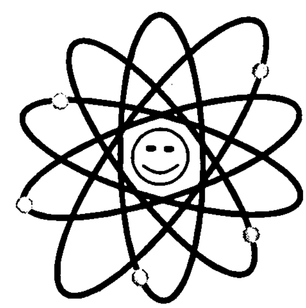
Section 2.3: Building Molecules

Activity Guide AB-A2

The second Activity Guide concentrates on how atoms bond to other atoms. The students will first learn how the shell structure of the electrons leaves most atoms lacking in something which makes them "happy" (i.e. the electron shells are not complete). The Atom Building Game board will help to visualize this. The students will then see how a simple molecule, water, makes both the hydrogen and the oxygen atoms "happier" than if they were single particles.

RULES FOR HAPPY ATOMS

We learned about how atoms are made from protons, neutrons, and electrons in Activity **A1.** Let's learn how atoms bond together.



You can think of atoms as having a list of things that they want. The list looks like this:

- Atoms want the same number of electrons as protons (they want to be neutrally charged).
- Atoms want to have full electron levels, but they want to be neutral more than they want to have full levels.

A2.1: Build a neutral atom with two protons. Into what level do the electrons go?

(The neutral atom should have two protons, two or three neutrons, and two electrons.) The electrons fill the lowest level.

A2.2: Is this level filled or not? Does this atom get what it wants from the list above?

The lowest level is filled. This atom is "happy".

A2.3: Now build a neutral atom with three protons? Does this atom get what it wants from the list above?

(The neutral atom should have three protons, three or four neutrons, and three electrons. The electrons fill the lowest level and one spot in the second level.) This atom is not "happy", since the second level is partially filled.

MAKING MOLECULES

Up until now, we have talked about single atoms by themselves. But atoms can get what they want on their list by sharing electrons with other atoms. If two or more atoms share electrons, they form a **bond.** When atoms form bonds, they form **molecules.**

A2.4: Have you ever heard of the formula $\mathbf{H_2O}$? What is this the formula for?

water

Molecule - two or more atoms bonded together

H_2O is a molecule. It is made up of two hydrogen atoms (H) and one oxygen atom (O).

ELEMENTS and COMPOUNDS

Materials are made of either elements or compounds. Elements are made of up only one type of atom, while compounds are made of two or more types of atoms. Either one can have the atoms bound together into molecules.

Element - a material made from only one type of atom

Compound - a material made from a combination of more than one type of atom

A2.5: Fill in the table below. Some familiar materials are listed, as well as what types of atoms they are made up of. List whether they are elements or compounds.

Common Name	What atoms is it made of?	Element or Compound?
Water	Hydrogen (H) and Oxygen (O)	*compound*
Salt	Sodium (Na) and Chlorine (Cl)	*compound*
Diamond	Carbon (C)	*element*
Oxygen	Oxygen (O)	*element*
Sugar	Carbon (C), Hydrogen (H), and Oxygen (O)	*compound*
Iron	Iron (Fe)	*element*
Rust	Iron (Fe) and Oxygen (O)	*compound*

HYDROGEN

A2.6: Hydrogen is an element with one proton in the nucleus. Build a neutral hydrogen atom. Does the hydrogen atom have a filled electron level? If not, how many electrons does it want?

The lowest level has only one electron, and is not filled. It wants one more electron.

OXYGEN

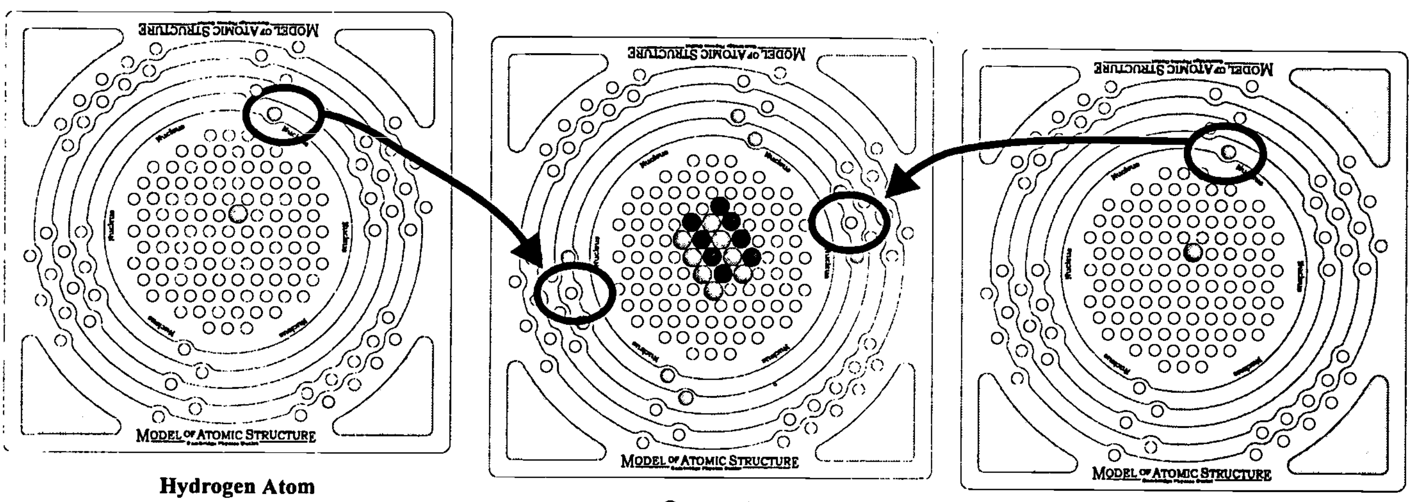
A2.7: The oxygen nucleus has eight protons. Build a neutral oxygen atom. Does the oxygen atom have its last level filled? If not, how many electrons does it want to fill the last level?

The last (second) level is not filled, it needs two more electrons to fill it.

THIS NEXT ACTIVITY REQUIRES THREE GROUPS TO WORK TOGETHER. YOU MAY NEED TO WAIT UNTIL OTHER GROUPS HAVE GOTTEN TO THIS POINT SO THAT YOU CAN SHARE YOUR BOARDS.

A2.8: Now take three Atom Model boards and put them together. Build a neutral oxygen atom on the board in the middle. Build neutral hydrogen atoms on the other two boards. Are any of these atoms happy according to our rules above?

None of the atoms have complete levels.



Hydrogen Atom

Oxygen Atom

Hydrogen Atom

A2.9: Take the electrons from the hydrogen atoms and fill the empty spaces in the oxygen levels. Does the oxygen have a complete shell now?

Oxygen now has a complete shell.

A2.10: Is the oxygen neutral now?

The oxygen atom is not neutral now. (it has a charge of -2).

A2.11: Is the entire molecule neutral?

The molecule is neutral: it has ten protons and ten electrons for a net charge of zero.

This is how molecular bonding works. The atoms share electrons, to balance out the electron levels. Electrons spend some of their time near the oxygen atom, and some of their time near the hydrogen atoms. Some of the time, all the atoms get what they want. This is why atoms form bonds. The H_2O molecule is just one example of a bond.

Section 2.4: The Atomic Challenge Game

Activity Guide AB-G1

This activity is the first of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of Atomic Structure.

The Activity Guide for this game is merely a set of rules, and two charts for reference. Both games are played similarly at Levels A, B, and C. The rules don't change between the levels, but the understanding that the students should have going into the games will be deeper at each succeeding level. Since the rules of atomic structure are built into the structure of the game, as the students' understanding deepens, the lessons that will be reinforced by playing the game deepens as well.

The students should have worked through Activities A1 and A2 before playing this game.

This activity is a game for two to five players. To play, we already need to know how atoms are built out of protons, neutrons, and electrons. If we haven't already learned the following vocabulary, we will need to learn it now:

Isotopes - Atoms with the same number of protons, but different numbers of neutrons. Isotopes are the same element, but have different mass.

Stable Isotope - Only certain isotopes are stable, others will spontaneously decay into something else.

RULES FOR ATOMIC CHALLENGE

- Start with one Atom Building Game board per group, with a full set of marbles and a deck of "Nuclear Reaction" cards. The board should be empty at the start of the game.
- Shuffle the cards, and deal each player five cards.
- Each player is given four protons (red marbles), four neutrons (blue marbles), and four electrons (yellow marbles).

- The players take turns playing cards. When it is your turn:
  - Any card from your hand can be played, i.e. "Add 3 Neutrons" or "Subtract 1 Electron". Take a new card after playing one (you should always have five cards in your hand).
  - The marbles that are added must come out of your hand, and any marbles subtracted go back into the your hand.
  - You can earn points from playing your cards. You get:
    1 point if you change the atom from unstable to stable with your play
    1 point if you change the atom from charged to neutral with your play
    or 3 points if the atom is *both* stable and neutral at the end of your play
  - You *must* declare what you made: the name of the element, what isotope (i.e. what mass), and whether it is neutral or what charge there is on the atom.
  - If someone challenges your declaration, and they are right (you are wrong), they get the points instead of you.
  - If you don't like any of your cards, you can trade a card for another one from the deck instead of playing one at your turn.
- The first player to 15 points wins.

You will need to refer to the next two pages to play this game.

The **Reduced Periodic Table** shows all the elements in the periodic table up to Xenon. These are the elements that can be made with the Atom Building Game. The chart also shows the isotopes that are stable, and the atomic number for each element. This chart is the most important chart to play the game with.

The **Partial Chart of the Nuclides** gives more detail about the elements up to Neon. You can read the numbers of protons and neutrons directly off of the chart, and tell whether the isotopes are stable or not. For the unstable isotopes, the types of instability are shown as well.

Reduced Periodic Table

Key: 92, 94-100 — Stable Mass Numbers; Mo — Element Symbol; 42 — Atomic Number

1,2 **H** 1																	3,4 **He** 2
6,7 **Li** 3	9 **Be** 4											10,11 **B** 5	12,13 **C** 6	14,15 **N** 7	16-18 **O** 8	19 **F** 9	20-22 **Ne** 10
23 **Na** 11	24-26 **Mg** 12											27 **Al** 13	28-30 **Si** 14	31 **P** 15	32-34, 36 **S** 16	35,37 **Cl** 17	36,38, 40 **Ar** 18
39,41 **K** 19	40,42-44,46, 48 **Ca** 20	45 **Sc** 21	46-50 **Ti** 22	51 **V** 23	50, 52-54 **Cr** 24	55 **Mn** 25	54,56-58 **Fe** 26	59 **Co** 27	58,60-62,64 **Ni** 28	63,65 **Cu** 29	64,66-68,70 **Zn** 30	69,71 **Ga** 31	70,72-74,76 **Ge** 32	75 **As** 33	74,76-78,80, 82 **Se** 34	79,81 **Br** 35	78,80, 82-84, 86 **Kr** 36
85 **Rb** 37	84, 86-88 **Sr** 38	89 **Y** 39	90-92, 94,96 **Zr** 40	93 **Nb** 41	92, 94-100 **Mo** 42	none **Tc** 43	96,98-103,104 **Ru** 44	103 **Rh** 45	102,104-106,108, 110 **Pd** 46	107,109 **Ag** 47	106,108, 110-112, 114,116 **Cd** 48	113 **In** 49	112,114-120,122, 124 **Sn** 50	121 **Sb** 51	120,122, 124-126, 128,130 **Te** 52	127 **I** 53	124,126, 128-132, 134,136 **Xe** 54

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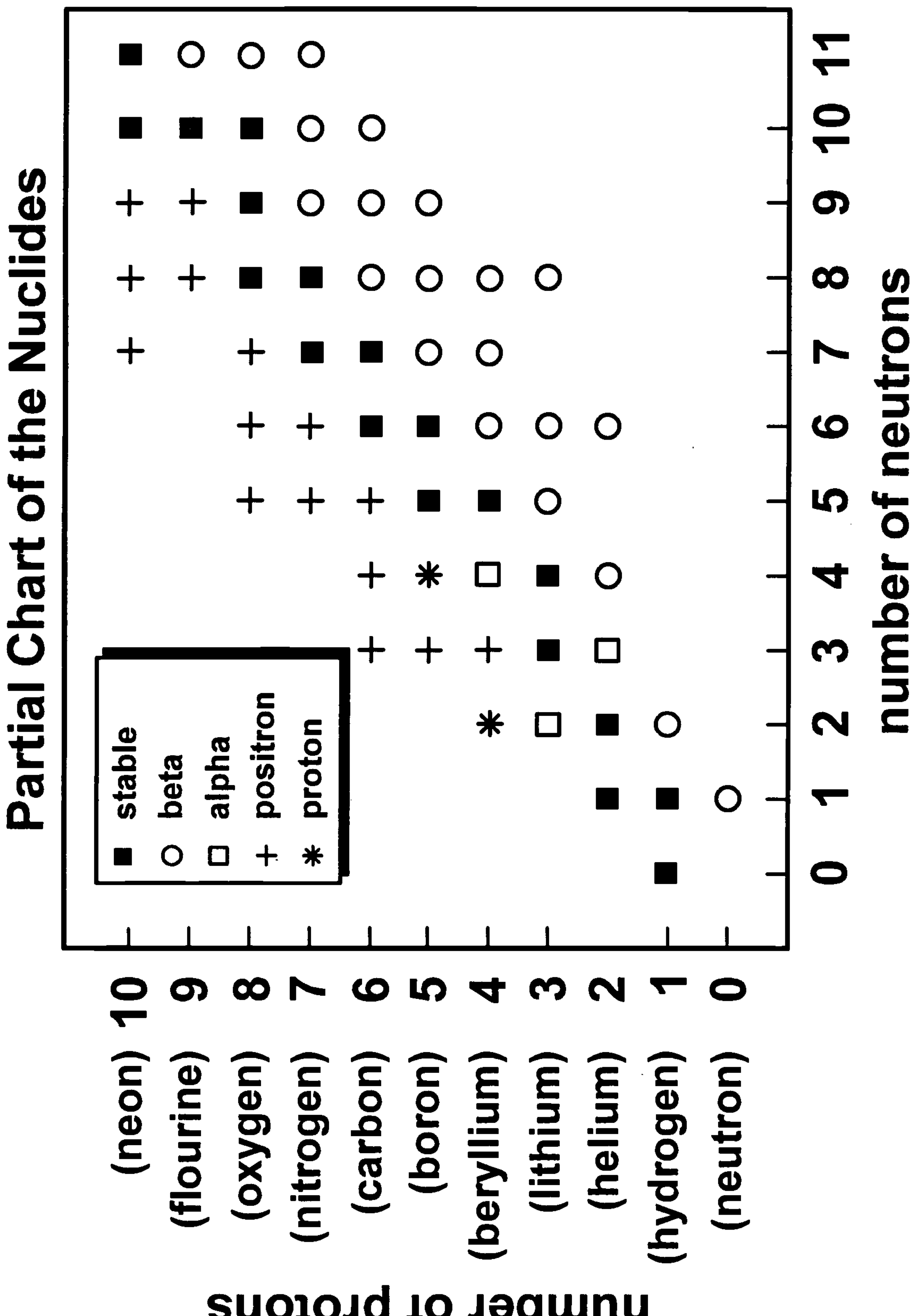

Partial Chart of the Nuclides
stable
beta
alpha
positron
proton
number of neutrons
0 1 2 3 4 5 6 7 8 9 10 11
number of protons
(neon) 10
(flourine) 9
(oxygen) 8
(nitrogen) 7
(carbon) 6
(boron) 5
(beryllium) 4
(lithium) 3
(helium) 2
(hydrogen) 1
(neutron) 0

Section 2.5: The Photons and Lasers Game

Activity Guide AB-G2

This activity is the second of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of Atomic Structure.

The Activity Guide for this game is merely a set of rule. Both games are played similarly at Levels A, B, and C. The rules don't change between the levels, but the understanding that the students should have going into the games will be deeper at each succeeding level. Since the rules of atomic structure are built into the structure of the game, as the students' understanding deepens, the lessons that will be reinforced by playing the game deepens as well.

The students should have worked through Activities A1 and A2 before playing this game.

This activity is a game for two to five players. To play, we must understand how electrons fill the shells of atoms. In playing, we will see how we can excite atoms, and then trigger them to release the energy that was stored when we excited them.

RULES FOR PHOTONS AND LASERS

- Start with one Atom Building Game board per group, with a full set of marbles and a deck of "Photons and Lasers" cards.
- The board should be set up as neutral neon-20 at the start of the game (10 protons, 10 neutrons, and 10 electrons). The atom should be in the ground state, i.e. all of the electrons should be placed in the lowest layers possible -- this should fill the first and second levels completely.
- Shuffle the cards, and deal each player five cards.
- The players take turns playing cards. When it is your turn:
- Any card from your hand can be played, i.e. "Pump one" or "Lase three". Take a new card after playing one (you should always have five cards in your hand).
- When you play a pump card:
  You pump a single electron up.
  The number of levels it is moved up is the same as on the card.
  You declare your move, i.e. "I am pumping an electron from level 1 to level 2".
  You never earn any points for pumping.
- When you play a lase card:
  You pick one level, and drop *all* electrons from this level the number of levels as on the card.
  The number of electrons that you can drop is limited by the number of electrons on the starting level, and by the number of empty holes on the target level.
  You declare you move, i.e. "I am lasing all electrons from level 3 to level 1".
  You earn points equal to the number of levels dropped x the number of electrons dropped.

- If you don't like any of your cards, you can trade a card for another one from the deck instead of playing one at your turn.
- The first player to 20 points wins.

Note: if you play a lase card, you only get to drop electrons between two levels. You do *not* get to drop all the electrons on the board. (i.e. playing a "LASE 3" card can drop all the marbles from level 5 to level 2 *or* from level 4 to level 1, but not both). You must also have enough empty holes in the lower levels to accommodate the electrons that you lase.

Let's try an example. Set up the board in ground state neon and play along. In the ground state, there are:

2 in level 1	*8* in level 2	*0* in level 3	*0* in level 4	*0* in level 5

Player 1 plays a "PUMP 1" card. She decides to move an electron from the second level to the third level. She then draws another card.

Player 2 plays a "PUMP 1" card. He decides to move another electron from the second to third. He then draws another card

Player 3 plays a "PUMP 3" card. He decides to move an electron from the first to the fourth levels. He then draws another card.

Player 4 plays a "PUMP 2" card. She decides to move an electron from the second level to the fourth level. She then draws another card.

The board now looks like this:

1 in level 1	*5* in level 2	*2* in level 3	*2* in level 4	*0* in level 5

Player 1 now plays a "LASE 2" card. She knows that she can earn the most points by dropping the most marbles. If she drops electrons from level 3 to level 1, she is limited to one electron, because there is only one vacancy at level 1 (even though there are two electrons at level 3). If she drops electrons from level 4 to level 2, she is limited to two electrons, because there are only two electrons at level 4 (even though there are three vacancies at level 2). There are no electrons at level 5 to drop, so she doesn't consider dropping from level 5 to level 3. She decides to drop two electrons from level 4 to level 2, thus scoring 4 points. This leaves the board like so:

1 in level 1	*7* in level 2	*2* in level 3	*0* in level 4	*0* in level 5

Player 1 now has 4 points, and the other players have zero. Player 1 draws another card, and the game continues with Player 2.

Chapter 3
Level B Activities

Section 3.1: Learning Goals for Level B

The Atomic Structure Curriculum provides a basic introduction to atoms. We introduce the key concepts of forces in the atom:

- Like charges repel and opposite charges attract,
- Electrons prefer to fill up the lower shells first,
- Electrons are attracted to the nucleus by the electromagnetic force,
- Protons and neutrons are held together by the strong nuclear force.

We also introduce familiarity with atoms, isotopes, and ions:

- Elements are defined by the number of protons in the nucleus
- Isotopes are atoms of the same element, with different numbers of neutrons,
- Ions are atoms of the same element with non-zero electric charge.

We then discover how elements can be grouped by valence, and how bonding occurs:

- First ionization energy for different elements shows a pattern,
- The closer electron levels are harder to ionize,
- Atoms prefer to have a full shell of electrons,
- The chemical properties of atoms are based on number of valence electrons,
- The periodic table organizes groups of atoms according to their valences,
- Bonding is due to this preference to give or take electrons to fill levels.

We use the Atom Building Game board as an atomic model for these activities. The board reinforces the rules of atomic structure visually, and the activities reinforce the rules by manipulative activities. The activities lead the students through a basic understanding of atomic structure and atomic bonding.

Apparatus:

- One Atom Building Game board per group, including one bag each of electrons, protons, and neutrons per group.
- One Activity Guide per student

Key Vocabulary for Level A

- **Atom:** Atoms are the building blocks of matter. An atom is a nucleus surrounded by electrons, usually with the number of electrons equal to the number of protons in the nucleus.
- **Nucleus:** The core of the atom. The nucleus is made of protons, which are positively charged, and neutrons, which have no charge. The nucleus is positively charged. The number of protons in the nucleus determines what the atom is (i.e. what element: Hydrogen, Oxygen, etc.).
- **Electrons:** Electrons are elementary particles. They are negatively charged (charge of -1 per electron). They can be free particles, or they can be bound to a nucleus. When electrons are bound to a nucleus, they can live only in specific levels, which are determined by the positive charge of the nucleus and the number of other electrons already bound to the nucleus.
- **Protons:** Protons are positively charged particles (charge of +1 per proton). Protons and neutrons form the nucleus. Protons are far more massive than electrons (about 2000 times more massive).
- **Neutrons:** Neutrons are neutrally charged particles. Protons and neutrons form the nucleus. Neutrons have about the same mass as protons (i.e. about 2000 times the mass of electrons).
- **Elements:** If two nuclei have the same number of protons, they are the same element. The number of neutrons in the nucleus does not change the element. The number of electrons surrounding the nucleus does not change the element.
- **Isotopes:** If two nuclei of the same element have the same number of neutrons, they are the same isotope. Different isotopes are nuclei of the same element (same number of protons) that have

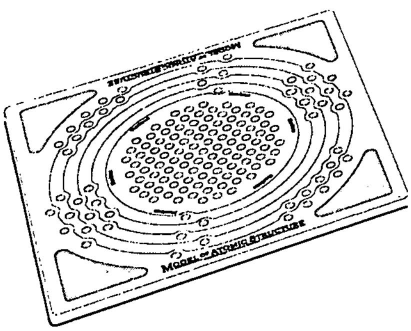
different mass (different number of neutrons). Isotopes have identical chemical properties, since they have the same charge.

- **Atomic Number:** The number of protons in the nucleus. The element is determined by the atomic number.
- **Mass Number:** The number of protons in the nucleus plus the number of neutrons in the same nucleus. The isotope of an element is determined by the mass number.
- **Electromagnetic Force:** The force that attracts electrons to the nucleus, and repels particles with the same sign charge from each other.
- **Strong Nuclear Force:** The attractive force that holds together the protons and neutrons in the nucleus. The strong nuclear force acts over very short range only, over the dimension of the nucleus.
- **Valence:** The number of electrons in the outermost ring of electrons, (sometimes the number of remaining holes in this ring).
- **Periodic Table:** A catalog of all the elements, organized in order of increasing atomic number, and grouped according to similarities of chemical properties.
- **Charge:** A basic property of nuclear physics. Electrons have -1 charge unit each, protons have +1 charge unit each, and neutrons have 0 charge unit each. Any two particles with the same nonzero charge repel each other, and any two particles with opposite charges attract each other. Every nucleus is positively charged. It is the positive charge of the nucleus that attracts electrons to it to make ions or atoms.
- **Ion:** An ion is an atom with a different number of electrons than protons. Since the electron and proton charges don't balance out, the ion has net charge. If an ion has the same number of electrons as protons in the nucleus, it is neutral, and we say it is an atom, not an ion. If an ion has fewer electrons in the shell than protons in the nucleus, the ion is positively charged. If an ion has more electrons in the shell than protons in the nucleus, the ion is negatively charged.
- **Ionize:** To take away electrons from or add electrons to an atom. This turns a neutral atom into a charged ion. When all the electrons have been stripped from an atom, the atom has been "fully ionized."
- **Bond, bonding:** Two or more atoms can share electrons so that for each of them, the last electron level appears to be full. When atoms "cooperate" in such a manner, they form a bond. When two or more atoms form a bond, they stick together to form a cluster, which we call a molecule. Bonding is the process of forming a bond.
- **Molecule:** The cluster of atoms which forms when they bond. Two very common molecules are NaCl and H_2O. NaCl is the chemical name for table salt, a molecule formed when one sodium (Na) atom bonds with one chlorine (Cl) atom. H_2O is the chemical name for water, a molecule which forms when two hydrogen (H) atoms bond with one oxygen (O) atom.

Section 3.2: Forces in the Atom

Activity Guide AB-B1

The first Activity Guide concentrates on the internal structure of the atom. The students should learn where in the atom the electrons, neutrons, and protons reside, and how the electrical charge is determined. A few simple atoms will be built on the Atom Building Game board for visualization. The students will discover the need for the strong nuclear force.



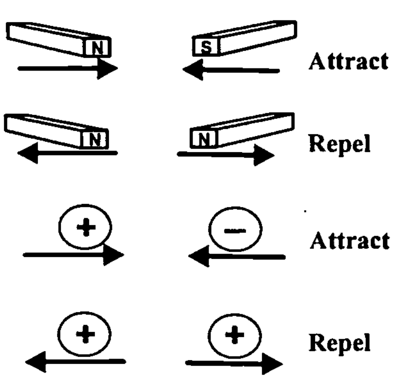
Everything is made of atoms. Atoms are the building blocks of nature.

The ancient Greeks once thought that atoms were the smallest pieces of matter; that they were indivisible. We now know that even atoms are made up of smaller pieces. In these activities, we will learn how to build atoms from these pieces.

Atoms are incredibly tiny, far too small for us to do simple experiments on them. Instead of building real atoms, we will use our model of the atom. You should have one Atom Model per group, along with three bags of marbles (red protons, blue neutrons, and yellow electrons). The rules for the activities below are the same rules that nature follows in building atoms -- but we will be able to see what we are doing by using the model.

Open up the bags of marbles, and put a few of each type in the corner pockets of the Atom Model.

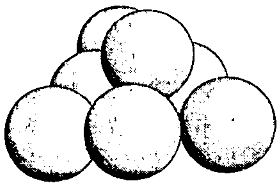
ELECTRIC FORCES



Have you ever experimented with magnets? Electric charges obey similar rules to magnets. If you remember, magnets attract North to South and South to North, but repel North to North and South to South. Electric charges are labeled plus or minus (positive or negative) instead of North and South.

Electric charges obey these rules:

- positive charges repel other positive charges
- negative charges repel other negative charges
- positive charges attract negative charges

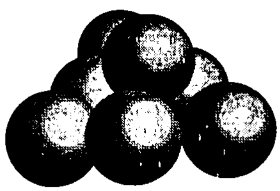

Protons (red marbles) have positive electric charge

B1.1: Take two protons (red marbles) in your hands. According to the rules of electric forces, should you feel a force? If so, do the protons repel or attract each other?

repel, since they are like charges

B1.2: Now take two electrons (yellow marbles) in your hands. Do they repel or attract one another?

repel, since they are like charges

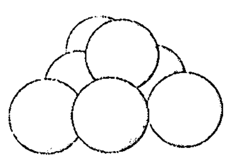

Neutrons (blue marbles) have no electric charge

B1.3: Now take two neutrons (blue marbles). Do they repel or attract?

neither, since neutrons are uncharged

B1.4: How about a proton (red marble) and a neutron (blue marble). Do they repel or attract?

neither, since the neutron is uncharged

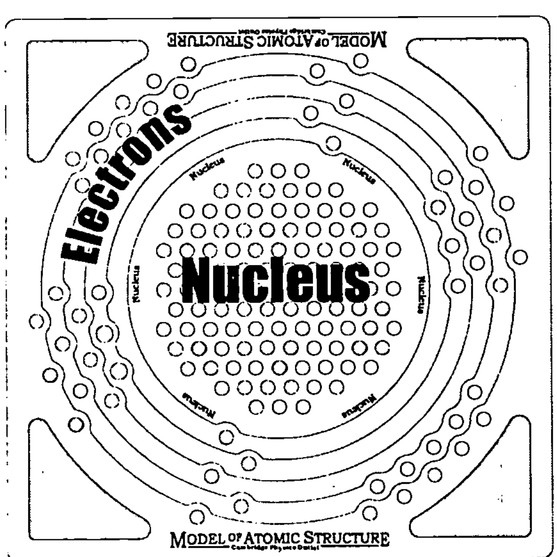

Electrons (yellow marbles) have negative electric charge

B1.5: How about a neutron and an electron?

neither, since the neutron is uncharged

B1.6: How about a proton and an electron?

attract, since they have opposite charges



Atoms have a nucleus and electrons. Only protons and neutrons live in the nucleus. On the board, this means that only red marbles (protons) and blue marbles (neutrons) go in the center. Electrons are never found in the nucleus.

B1.7: Is the nucleus positively charged or negatively charged?

Positively charged

Nucleus - the core of the atom, containing protons and neutrons

START BUILDING AN ATOM:

Make a nucleus that has three protons in it on the model. Make sure that the marbles go into holes on the model.

B1.8: What is the charge of this nucleus?

The charge is +3, since each proton has a charge of +1

B1.9: How many electrons should surround this nucleus to make a neutral atom?

three electrons are necessary to neutralize the three protons in the nucleus.

B1.10: Does the nucleus attract or repel electrons?

attract, since the charges are opposite

ADD NEUTRONS TO THE ATOM:

Atoms usually have about the same number of neutrons as protons in the nucleus. Sometimes they have a few more neutrons, sometimes the same number, rarely less.

Continue building your atom with three protons and three electrons.

B1.11: How many neutrons are probably in this atom? Add them.

There are probably three. Four is also acceptable.

B1.12: What is the charge of the atom now?

It is unchanged. Neutrons have no charge, so the net charge is still zero.

B1.13: Should the nucleus hold itself together or blow itself apart? Why?

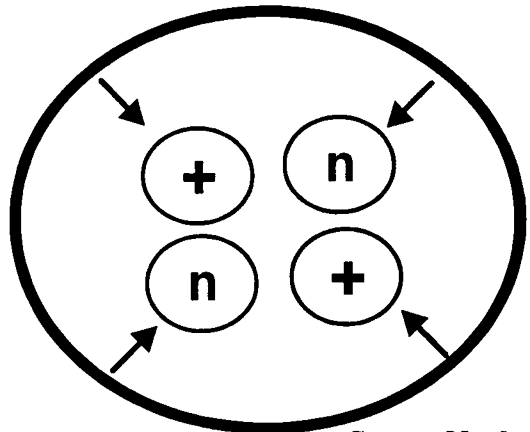
The nucleus should probably blow apart, based on what we know.

The protons in the nucleus all repel each other.

There is a second force (besides the electromagnetic force) which is necessary to assemble an atom. Scientists call this the **Strong Nuclear Force.** This is an attractive force that holds protons to protons, protons to neutrons, and neutrons to neutrons. It has two main features:

1) It is much stronger than the electromagnetic force (so much stronger that it completely overpowers the repulsion between protons), and

2) It is a very short range force, and nearly disappears outside of the nucleus.



Strong Nuclear Force

Strong Nuclear Force - the short range force that holds the nucleus together

WHERE DO THE ELECTRONS GO?

You know that the nucleus is positive and that electrons are negative. This means that the electrons and the nucleus are attracted to each other. This is how an atom is held together.

Electrons cannot live in the nucleus. Let's figure out where the electrons prefer to go.

Start with your neutral atom of three protons, three neutrons, and three electrons.

B1.14: If the lower levels for the electrons are closer to the nucleus, where do you think the electrons should go? Why?.

The electrons should fill up the lower (inner) layers first, then fill outwards.

Section 3.3: Atoms, Isotopes, and Ions

Activity Guide AB-B2

*The second Activity Guide adds to the lessons from **AB-B1**, by defining many of the common terms used in atomic structure. Students will gain more familiarity with the rules for building atoms using the manipulatives of the Atom Building Game.*

NAMING ATOMS

We label atoms by the number of protons in their nucleus. If two nuclei have the same number of protons, we say that they are the same element, even if the number of neutrons is different. Atoms that have the same number of protons and different numbers of neutrons are different **isotopes** of the same element.

Element - atoms with the same number of protons are of the same element

Isotope - atoms of the same element with different numbers of neutrons are different isotopes of that element

Each element is given a name. These are the names of the first four elements:

Number of protons	Name
1	hydrogen
2	helium
3	lithium
4	beryllium

Right now, we know of 108 different elements. We will learn more about other elements later.

B2.1: Build a neutral atom with three protons and three neutrons. What element is this?

lithium

B2.2: Where do you think the electrons should go? Why?

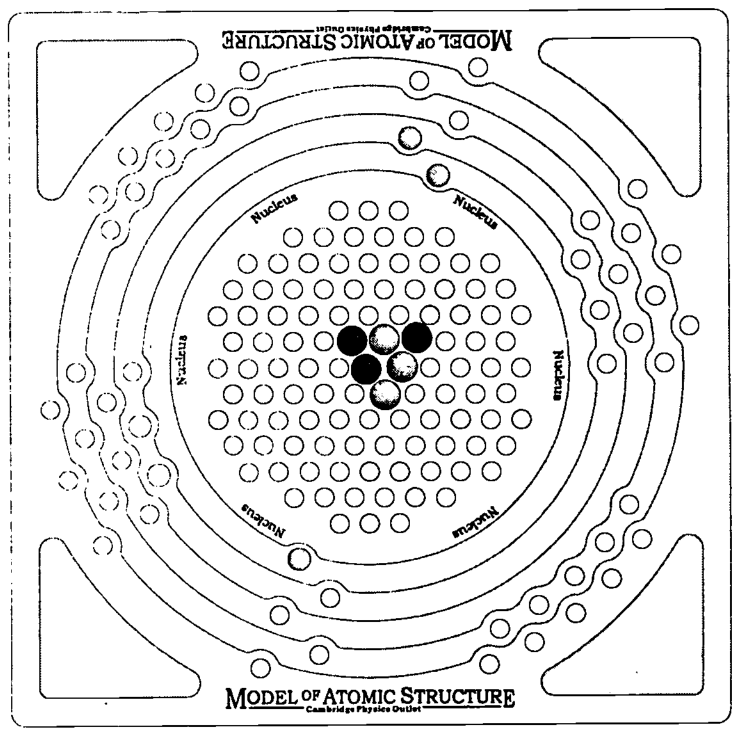
two in the lowest level, and one in the second level. the electrons fill from lowest up

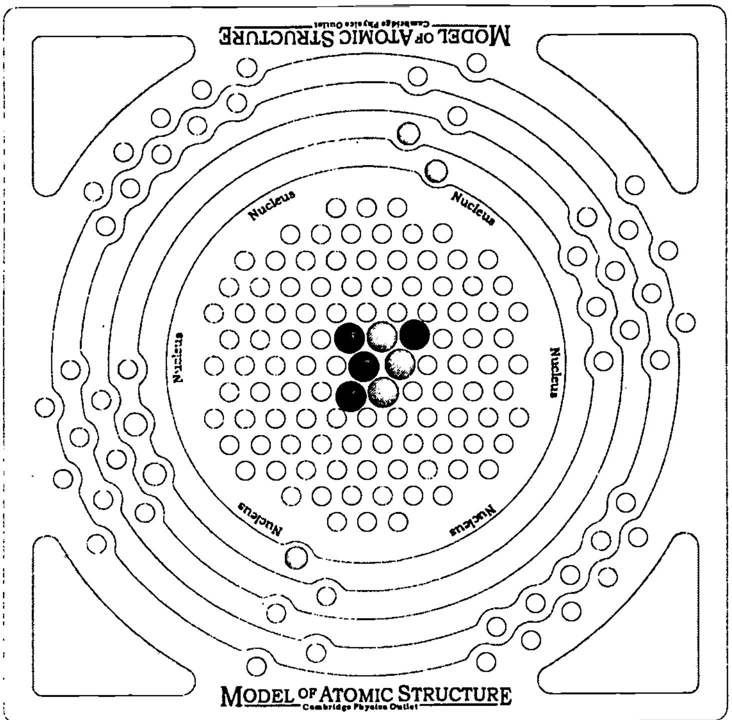
B2.3: Now add another neutron to the nucleus? What is the charge on the atom? Is this the same element as before? If not, what element is it?

the charge is the same (zero). it is still lithium, just a different isotope.

The number of protons in a nucleus is called the **atomic number** for that element. The number of protons plus the number of neutrons in a nucleus is called the **mass number** for the isotope of that element. We can tell isotopes apart by their mass number. For example, lithium has two isotopes, which are called "lithium-six" and "lithium-seven".

The figure at the right shows lithium-six.





The figure at the left shows lithium-seven.

B2.4: How many neutrons are in lithium-six and lithium-seven?

lithium-six has 3 neutrons, lithium-7 has 4

B2.5: Build a neutral lithium atom (either lithium-six or lithium-seven). Where do you think the electrons should go?

Two in the lowest level, the third on the second level.

B2.6: Now take away the outermost electron. What is the charge of the atom? What element is it?

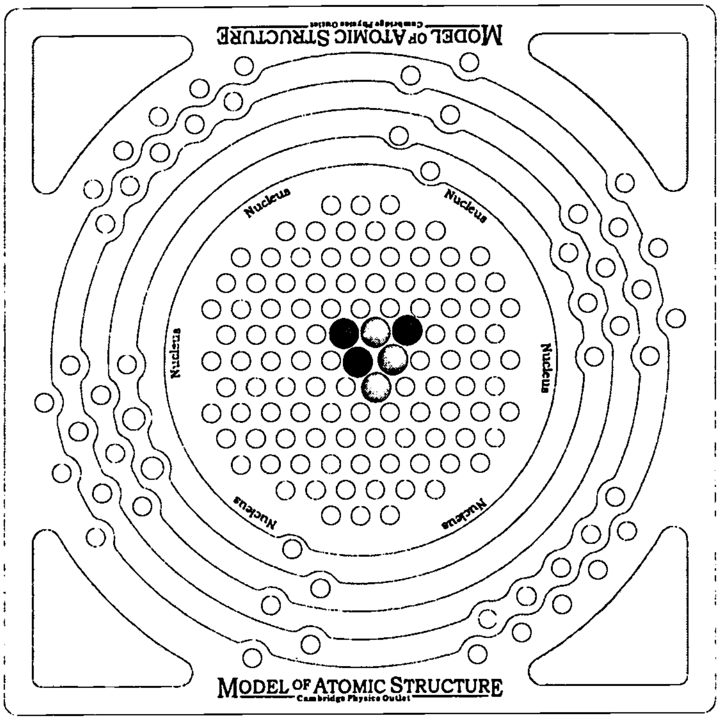
The charge is now +1. It is still lithium, it just isn't neutral anymore.

ATOMS and IONS

An atom that is not neutral is called an ion. Remember that the element name is determined only by the number of protons. This means that ionizing a neutral atom (adding or taking away electrons) does not change the element -- it only changes the charge.

Ion - an atom that is not neutral (too many or too few electrons)

If an atom has all of its electrons taken away, the atom is **fully ionized.**



The figure at the left shows lithium-six fully ionized.

B2.7: What is the charge of a fully ionized lithium ion?

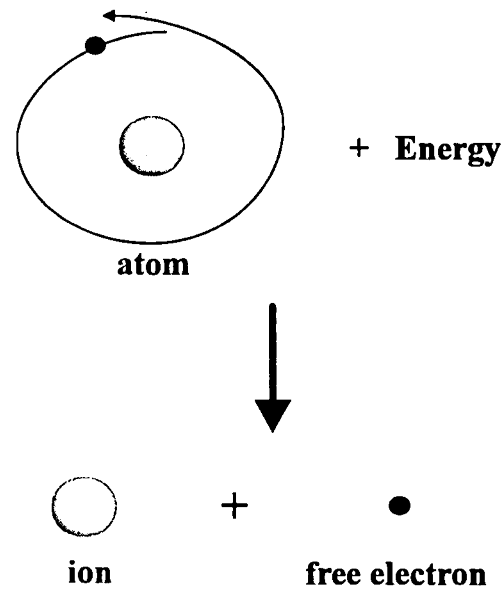
the charge is +3

Section 3.4: Valence, Chemistry, and the Periodic Table

Activity Guide AB-B3

The third Activity Guide concentrates on how atoms bond to other atoms. The students will explore the patterns that occur in the periodic table, by examining the number of valence electrons and by looking at the ionization potential of the elements. Simple bonding of molecules is explored.

FAMILIES OF ELEMENTS



We have learned that electrons are attracted to the nucleus. This means that it takes energy to pull electrons away from the atom.

One experiment that scientists like you can do (with the right equipment) is to measure the energy that it takes to pull one electron from a neutral atom.

B3.1: Build neutral neon (ten protons, ten neutrons, ten electrons). Now ionize it by removing one electron. Where did you remove the electron from?

the electron came from the second layer (which was full before removing it)

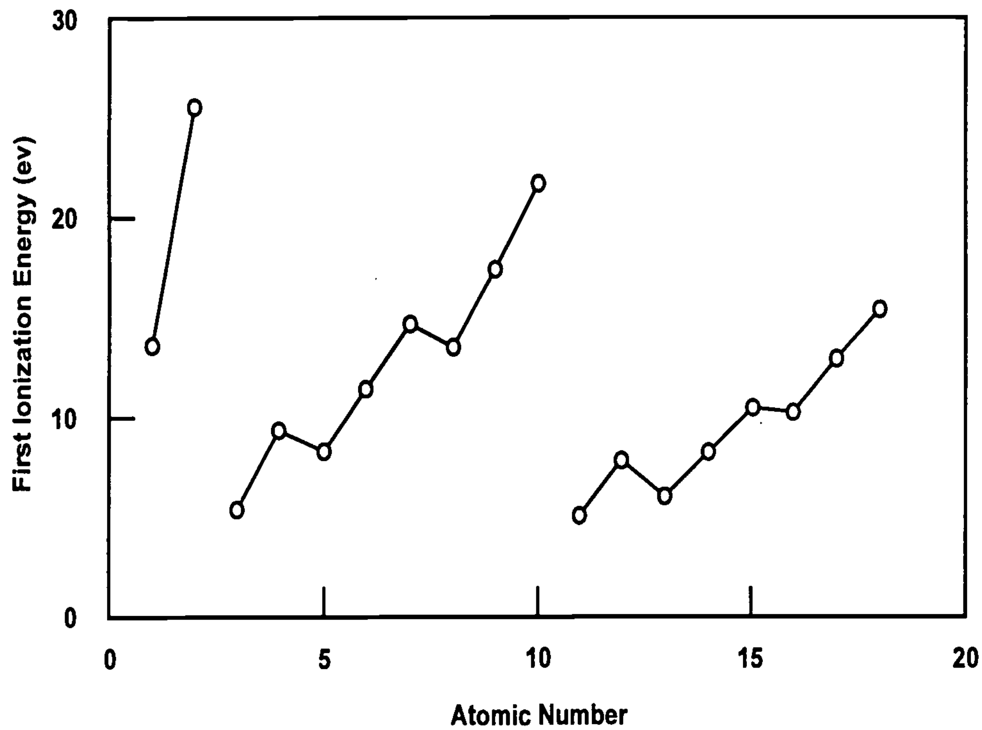
B3.2: Build neutral sodium (eleven protons, twelve neutrons, eleven electrons). Now ionize it by removing one electron. Where did you remove the electron from?

the electron came from the third layer (and it was the only electron on this layer)

B3.3: Do you think it takes more energy to ionize neon or sodium? Why?

the students are guessing at this point. it is only important to try to get them to think

the correct answer is that it takes more energy to ionize neon, for reasons given below.



The graph at the left shows the first ionization energy for each of the elements up to atomic number 18. (This is called the **first** ionization energy, since it is the energy required to remove the first electron from the neutral atom).

B3.4: From this graph, find the ionization energies for neon and sodium. Were you right in question **B3.3?**

???

B3.5: What are the units of energy shown in the graph? What were the units of energy that you have used before (such as in the Rollercoaster experiment)?

eV *Joules*

B3.6: Can you guess why it isn't convenient to use the same units of energy for both experiments?

Joules are too large. It is inconvenient to always need 10^{-17} factors

B3.7: Fill in the table below by building the atoms on the board to find the levels for the outermost electrons. You will have to refer to the graph above for the ionization energy.

Element	outermost level with an electron	total number of spaces in this level	total number of spaces filled in this level	1^{st} ionization energy (eV)
hydrogen	*1*	*2*	*1*	*13.6*
helium	*1*	*2*	*2*	*25.6*
lithium	*2*	*8*	*1*	*5.4*
beryllium	*2*	*8*	*2*	*9.5*
neon	*2*	*8*	*8*	*21.6*
sodium	*3*	*8*	*1*	*5.2*

B3.8: From this table and from the graph of ionization energy, we can look for patterns in ionization energy. Do you think that the ionization energy is about the same for all elements with the outermost electron at the same level?

no

B3.9: Do you think that the ionization energy increases as the number of electrons increases?

no

B3.10: Do you think that the ionization energy increases as the outermost level becomes more filled?

yes. this question and the last two attempt to get the students to find the pattern in the data

B3.11: Based on what you have learned, which element is lithium most like: helium, beryllium, or sodium?

sodium (both have one extra electron).

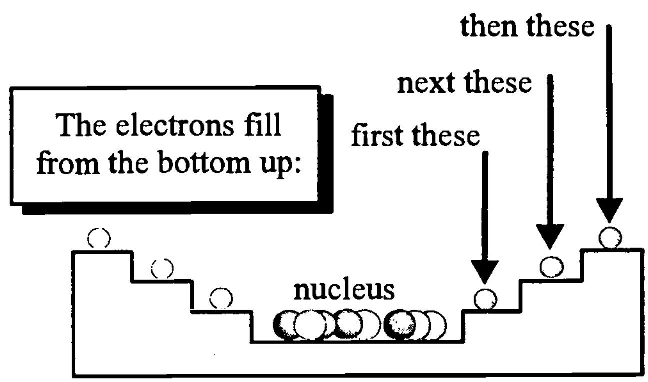
B3.12: Similarly, which element is neon most like: helium, beryllium, or sodium?

helium (both have full outer shells)

VALENCE AND CHEMISTRY

Let's recap what we have learned.

- A neutral atom has the same number of electrons as protons.
- Electrons don't live in the nucleus, only in the levels surrounding the nucleus.
- Since electrons are attracted to the nucleus, electrons fill the lowest (closest) levels first.
- Electrons must go into a hole. Once a given level is full, electrons have to start filling the next level.



We also found that there are patterns that occur in the energy necessary to ionize an atom. Do similar patterns exist elsewhere?

Yes! Chemists have long known that many elements behave very much the same. For example, lithium, sodium, and potassium are so similar that it can often be difficult to distinguish them. Similarly, chlorine, fluorine, and bromine are very similar.

B3.13: Build the following elements, and list the number of electrons and the number of remaining holes in the outermost level that is at least partially filled.

Element	Atomic Number	Electrons in Last Level	Holes in Last Level
hydrogen	1	*1*	*1*
helium	2	*2*	*0*
lithium	3	*1*	*7*
fluorine	9	*7*	*1*
neon	10	*8*	*0*
sodium	11	*1*	*7*
chlorine	17	*7*	*1*
argon	18	*8*	*0*
potassium	19	*1*	*17*

B3.14: What do helium, neon, and argon have in common in this table?

they all have 0 holes in last level

B3.15: What do lithium, sodium, and potassium have in common in this table?

they all have 1 electron in last level

The number of electrons in the last level of an atom is called its **valence.** Lithium, sodium, and potassium all have a valence of +1. Valence is sometimes given as a negative number, referring to the number of holes left in the last level. Fluorine and chlorine both have a valence of -1.

PERIODIC TABLE

Chemists have long noticed that some groups of elements behave similarly (long before electron levels were understood, in fact). The periodic table is an arrangement of the elements in such a way as to group together these elements that behave the same. A reduced periodic table (i.e. only those elements that we can construct with the Atom Building Game) is shown below.

Reduced Periodic Table

92,
94-100 — Stable Mass Numbers
Mo — Element Symbol
42 — Atomic Number

1,2 H 1																	3,4 He 2
6,7 Li 3	9 Be 4											10,11 B 5	12,13 C 6	14,15 N 7	16-18 O 8	19 F 9	20-22 Ne 10
23 Na 11	24-26 Mg 12											27 Al 13	28-30 Si 14	31 P 15	32-34, 36 S 16	35,37 Cl 17	36,38, 40 Ar 18
39,41 K 19	40,42-44,46, 48 Ca 20	45 Sc 21	46-50 Ti 22	51 V 23	50, 52-54 Cr 24	55 Mn 25	54,56-58 Fe 26	59 Co 27	58,60-62,64 Ni 28	63,65 Cu 29	64,66-68,70 Zn 30	69,71 Ga 31	70,72-74,76 Ge 32	75 As 33	74,76-78,80, 82 Se 34	79,81 Br 35	78,80, 82-84, 86 Kr 36
85 Rb 37	84, 86-88 Sr 38	89 Y 39	90-92, 94,96 Zr 40	93 Nb 41	92, 94-100 Mo 42	none Tc 43	96,98-103,104 Ru 44	103 Rh 45	102,104-106,108, 110 Pd 46	107,109 Ag 47	106,108, 110-112, 114,116 Cd 48	113 In 49	112,114-120,122, 124 Sn 50	121 Sb 51	120,122, 124-126, 128,130 Te 52	127 I 53	124,126, 128-132, 134,136 Xe 54

Look at the column on the left of the Periodic Table. The elements H, Li, Na, K, and Rb all have a valence of +1. These are called the Group 1 elements. The elements He, Ne, Ar, Kr, and Xe all have a valence of 0 (this is because there are no holes left - the outermost shells are all full).

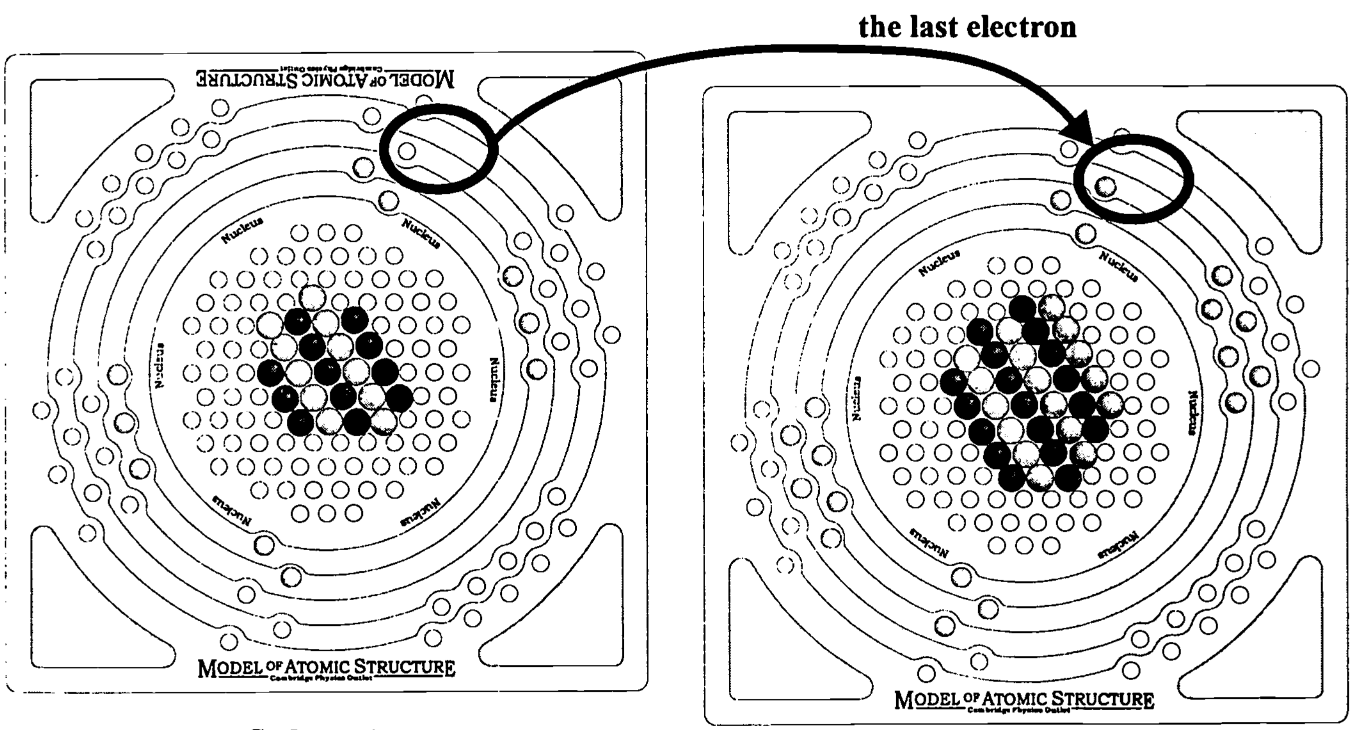
VALENCE AND CHEMICAL BONDS

You can think of the first ionization energy of an atom as a measure for how tightly the atom is holding on to all of its electrons. Noble gases such as helium, neon, and argon have a full outermost level. We see that noble gases have the highest first ionization energies of any group, which means that they want to keep all of their electrons. In other words, noble gases want to keep their last levels full.

Group 1 elements, such as hydrogen, lithium, and sodium, have one more electron than a full level. Of all the groups, group 1 elements all have the lowest first ionization energies. This means that group 1 elements readily give up their last electron. Once they give up their last electron, they have only full levels remaining.

Two or more atoms can share electrons so that each of them has full electron levels. This is called **bonding.** Atoms which bond together form a **molecule.** One common example of this is table salt, which is a bond between sodium and chlorine. Bonds between elements can be formed or broken, but a bond does not change elements themselves.

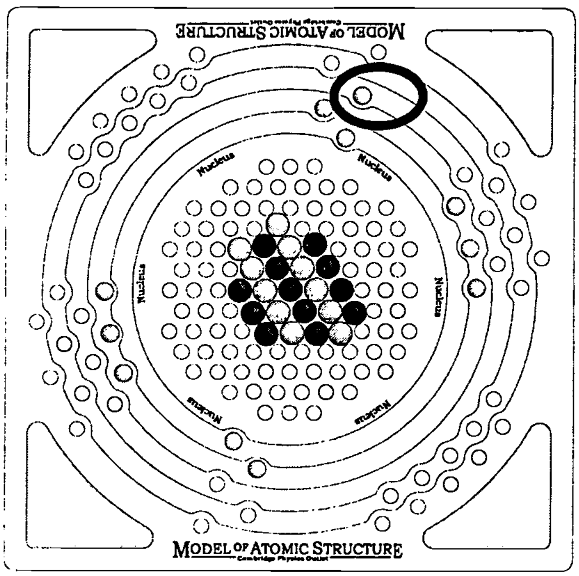
Using two Atom Building Games, build a neutral sodium atom on one board and a neutral chlorine atom on the other. Put the boards side by side.



Sodium Atom **Chlorine Atom**

B3.16: Describe how these two atoms bond together to form a molecule. Is the molecule neutral?

they share sodium's extra electron. this way, they both appear to have full outer shells, but the molecule is still neutral.



B3.17: Here is a neutral sodium atom. What is the charge on the atom? How full is the outermost shell of electrons?

charge = 0, outermost shell has one extra electron

B3.18: Look at the sodium atom in the salt molecule. What is the charge on the atom? How full is the outermost shell of electrons?

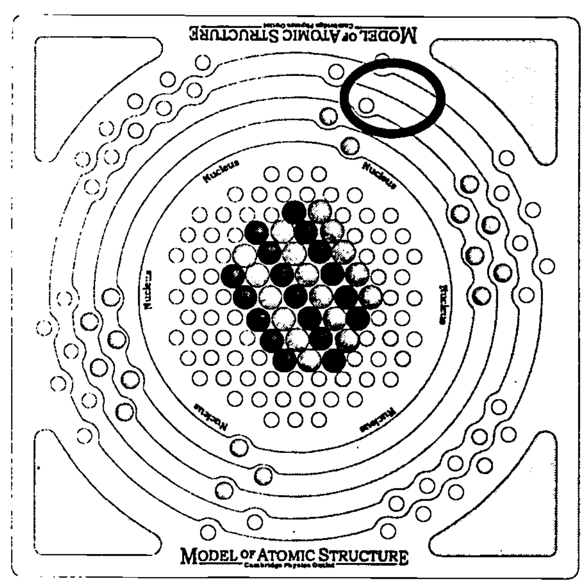
charge = +1, outermost shell filled

B3.19: Here is a neutral chlorine atom. What is the charge on the atom? How full is the outermost shell of electrons?

charge = 0, outermost shell has one hole

B3.20: Look at the chlorine atom in the salt molecule. What is the charge on the atom? How full is the outermost shell of electrons?

charge = -1, outermost shell full



B3.21: What other element might form the same kind of bond with sodium? Explain why?

fluorine, bromine, iodine. these all have valence of -1

B3.22: Build a neutral argon atom (atomic number 18). What elements might easily bond with argon? Why?

nothing will bond with argon. it has a complete shell (valence = 0) and wants no action.

Section 3.5: The Atomic Challenge Game

Activity Guide AB-G1

This activity is the first of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of Atomic Structure.

The Activity Guide for this game is merely a set of rules, and two charts for reference. Both games are played similarly at Levels A, B, and C. The rules don't change between the levels, but the understanding that the students should have going into the games will be deeper at each succeeding level. Since the rules of atomic structure are built into the structure of the game, as the students' understanding deepens, the lessons that will be reinforced by playing the game deepens as well.

*The students should have worked through Activities **B1** through **B3** before playing this game.*

The rules and comments are reproduced in Chapter 2 (Level A), since the rules are identical for this game as a Level A, Level B, or Level C activity.

Section 3.6: The Photons and Lasers Game

Activity Guide AB-G2

This activity is the second of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of Atomic Structure.

The Activity Guide for this game is merely a set of rule. Both games are played similarly at Levels A, B, and C. The rules don't change between the levels, but the understanding that the students should have going into the games will be deeper at each succeeding level. Since the rules of atomic structure are built into the structure of the game, as the students' understanding deepens, the lessons that will be reinforced by playing the game deepens as well.

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The rules and comments are reproduced in Chapter 2 (Level A), since the rules are identical for this game as a Level A, Level B, or Level C activity.

Chapter 4
Level C Activities

The Level B activities are suitable for both Level B and Level C students. There are no activities that are exclusively Level C as of this revision.

If this curriculum is being used to supplement a high school or (pre-calculus) college physics course, then additional experiments might be interleaved to make further connections to those lessons.

Some of these suggested supplements are:

- Spectroscopy and radiation from electronic excitation of atoms.
- Radioactive decay process and nuclear reactions.
- Electron level filling order, spectroscopic notation, and angular momentum.

Future revisions of this curriculum may incorporate some or all of these topics -- call CPO at 1-800-932-LABS for updated revision information.

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Chapter 5 Assessment

The Assessment Package for Atomic Structure is not complete as of this revision. Contact Cambridge Physics Outlet at 1-800-932-LABS for the latest revision information.

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Chapter 6
Reference

The Reference Section is not complete as of this revision. A good introduction to the key concepts taught throughout the Atomic Structure Curriculum is contained in Chapter 1. Contact Cambridge Physics Outlet at 1-800-932-LABS for the latest revision information.

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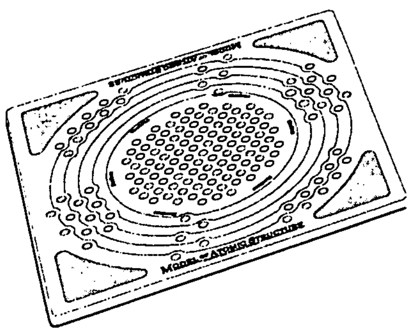
Name:

AB-A1

BUILDING ATOMS

What are nature's building blocks?

Everything is made of atoms. Atoms are the building blocks of nature.

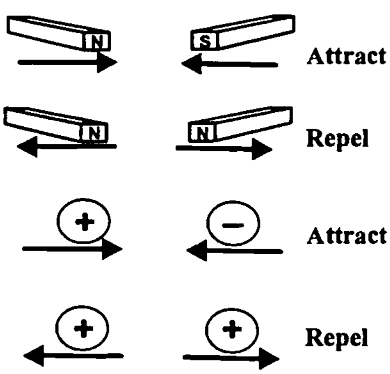


The ancient Greeks once thought that atoms were the smallest pieces of matter; that they were indivisible. We now know that even atoms are made up of smaller pieces. In these activities, we will learn how to build atoms from these pieces.

Atoms are incredibly tiny, far too small for us to do simple experiments on them. Instead of building real atoms, we will use our model of the atom. You should have one Atom Model per group, along with three bags of marbles (red protons, blue neutrons, and yellow electrons). The rules for the activities below are the same rules that nature follows in building atoms -- but we will be able to see what we are doing by using the model.

Open up the bags of marbles, and put a few of each type in the corner pockets of the Atom Model.

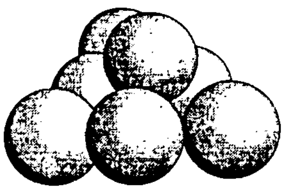
ELECTRIC FORCES



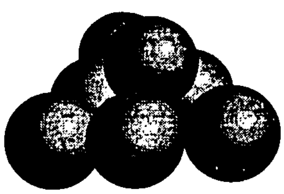
Have you ever experimented with magnets? Electric charges obey similar rules to magnets. If you remember, magnets attract North to South and South to North, but repel North to North and South to South. Electric charges are labeled plus or minus (positive or negative) instead of North and South.

Electric charges obey these rules:

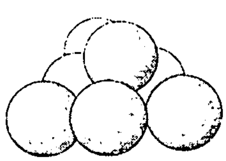
- positive charges repel other positive charges
- negative charges repel other negative charges
- positive charges attract negative charges



Protons (red marbles) have positive electric charge



Neutrons (blue marbles) have no electric charge



Electrons (yellow marbles) have negative electric charge

A1.1: Take two protons (red marbles) in your hands. According to the rules of electric forces, should you feel a force? If so, do the protons repel or attract each other?

____

A1.2: Now take two electrons (yellow marbles) in your hands. Do they repel or attract one another?

____

A1.3: Now take two neutrons (blue marbles). Do they repel or attract?

____

A1.4: How about a proton (red marble) and a neutron (blue marble). Do they repel or attract?

____

A1.5: How about a neutron and an electron?

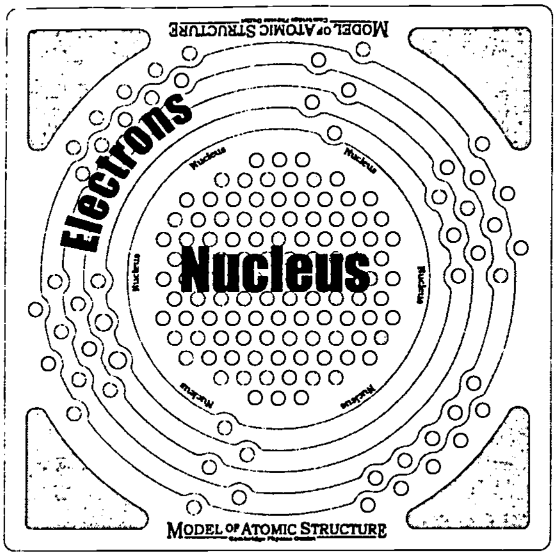
____

A1.6: How about a proton and an electron?

____

A1.7: If the electron is attracted to the proton, is the proton also attracted to the electron?

____



Atoms have a nucleus and electrons. Only protons and neutrons live in the nucleus. On the board, this means that only red marbles (protons) and blue marbles (neutrons) go in the center.

A1.8: Can electrons live in the nucleus?

A1.9: Is the nucleus positively charged or negatively charged?

Nucleus - the core of the atom, containing protons and neutrons

START BUILDING AN ATOM:

Make a nucleus that has three protons in it on the model. Make sure that the marbles go into holes on the model.

A1.10: What is the charge of this nucleus?

A1.11: Add three electrons to the model (where do they go?). What is the charge of the atom now?

A1.12: Now take away one of the electrons. What is the charge of the atom now?

ADD NEUTRONS TO THE ATOM:

Atoms usually have about the same number of neutrons as protons in the nucleus. Sometimes they have a few more neutrons, sometimes the same number, rarely less.

Continue building your atom with three protons and three electrons.

A1.13: How many neutrons are probably in this atom? Add them.

A1.14: What is the charge of the atom now?

A1.15: Add another neutron. What is the charge of the atom now?

WHERE DO THE ELECTRONS GO?

You know that the nucleus is positive and that electrons are negative. This means that the electrons and the nucleus are attracted to each other. This is how an atom is held together.

Electrons cannot live in the nucleus. Let's figure out where the electrons prefer to go.

Start with your neutral atom of three protons, three neutrons, and three electrons.

A1.16: If the lower levels for the electrons are closer to the nucleus, where do you think the electrons should go? Why?.

Name:

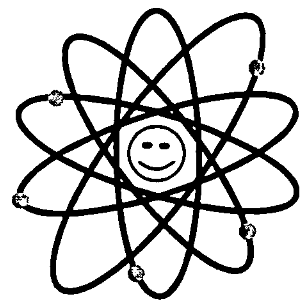
AB-A2

BUILDING MOLECULES

Putting together nature's building blocks

RULES FOR HAPPY ATOMS

We learned about how atoms are made from protons, neutrons, and electrons in Activity **A1.** Let's learn how atoms bond together.



You can think of atoms as having a list of things that they want. The list looks like this:

- Atoms want the same number of electrons as protons (they want to be neutrally charged).
- Atoms want to have full electron levels, but they want to be neutral more than they want to have full levels.

A2.1: Build a neutral atom with two protons. Into what level do the electrons go?

____

A2.2: Is this level filled or not? Does this atom get what it wants from the list above?

____

____

A2.3: Now build a neutral atom with three protons? Does this atom get what it wants from the list above?

____

____

MAKING MOLECULES

Up until now, we have talked about single atoms by themselves. But atoms can get what they want on their list by sharing electrons with other atoms. If two or more atoms share electrons, they form a **bond.** When atoms form bonds, they form **molecules.**

A2.4: Have you ever heard of the formula $\mathbf{H_2O}$? What is this the formula for?

____

Molecule - two or more atoms bonded together

H_2O is a molecule. It is made up of two hydrogen atoms (H) and one oxygen atom (O).

ELEMENTS and COMPOUNDS

Materials are made of either elements or compounds. Elements are made of up only one type of atom, while compounds are made of two or more types of atoms. Either one can have the atoms bound together into molecules.

Element - a material made from only one type of atom

Compound - a material made from a combination of more than one type of atom

A2.5: Fill in the table below. Some familiar materials are listed, as well as what types of atoms they are made up of. List whether they are elements or compounds.

Common Name	What atoms is it made of?	Element or Compound?
Water	Hydrogen (H) and Oxygen (O)	compound
Salt	Sodium (Na) and Chlorine (Cl)	
Diamond	Carbon (C)	
Oxygen	Oxygen (O)	
Sugar	Carbon (C), Hydrogen (H), and Oxygen (O)	
Iron	Iron (Fe)	
Rust	Iron (Fe) and Oxygen (O)	

HYDROGEN

A2.6: Hydrogen is an element with one proton in the nucleus. Build a neutral hydrogen atom. Does the hydrogen atom have a filled electron level? If not, how many electrons does it want?

____

____

OXYGEN

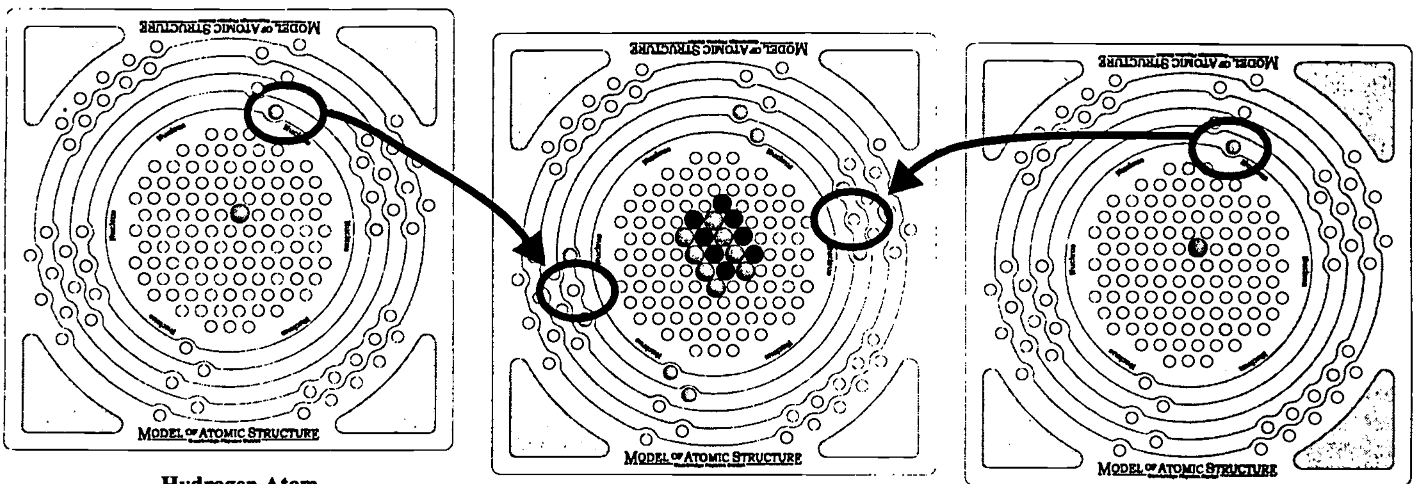
A2.7: The oxygen nucleus has eight protons. Build a neutral oxygen atom. Does the oxygen atom have its last level filled? If not, how many electrons does it want to fill the last level?

____

____

THIS NEXT ACTIVITY REQUIRES THREE GROUPS TO WORK TOGETHER. YOU MAY NEED TO WAIT UNTIL OTHER GROUPS HAVE GOTTEN TO THIS POINT SO THAT YOU CAN SHARE YOUR BOARDS.

A2.8: Now take three Atom Model boards and put them together. Build a neutral oxygen atom on the board in the middle. Build neutral hydrogen atoms on the other two boards. Are any of these atoms happy according to our rules above?



Hydrogen Atom **Oxygen Atom** **Hydrogen Atom**

A2.9: Take the electrons from the hydrogen atoms and fill the empty spaces in the oxygen levels. Does the oxygen have a complete shell now?

A2.10: Is the oxygen neutral now?

A2.11: Is the entire molecule neutral?

This is how molecular bonding works. The atoms share electrons, to balance out the electron levels. Electrons spend some of their time near the oxygen atom, and some of their time near the hydrogen atoms. Some of the time, all the atoms get what they want. This is why atoms form bonds. The H_2O molecule is just one example of a bond.

Name: _______________

ATOMIC CHALLENGE

A Game of Nuclear Reactions

This activity is a game for two to five players. To play, we already need to know how atoms are built out of protons, neutrons, and electrons. If we haven't already learned the following vocabulary, we will need to learn it now:

Isotopes - Atoms with the same number of protons, but different numbers of neutrons. Isotopes are the same element, but have different mass.

Stable Isotope - Only certain isotopes are stable, others will spontaneously decay into something else.

RULES FOR ATOMIC CHALLENGE

- Start with one Atom Building Game board per group, with a full set of marbles and a deck of "Nuclear Reaction" cards. The board should be empty at the start of the game.
- Shuffle the cards, and deal each player five cards.
- Each player is given four protons (red marbles), four neutrons (blue marbles), and four electrons (yellow marbles).
- The players take turns playing cards. When it is your turn:
  - Any card from your hand can be played, i.e. "Add 3 Neutrons" or "Subtract 1 Electron". Take a new card after playing one (you should always have five cards in your hand).
  - The marbles that are added must come out of your hand, and any marbles subtracted go back into the your hand.

- You can earn points from playing your cards. You get:
  1 point if you change the atom from unstable to stable with your play
  1 point if you change the atom from charged to neutral with your play
  or 3 points if the atom is *both* stable and neutral at the end of your play
- You *must* declare what you made: the name of the element, what isotope (i.e. what mass), and whether it is neutral or what charge there is on the atom.
- If someone challenges your declaration, and they are right (you are wrong), they get the points instead of you.
- If you don't like any of your cards, you can trade a card for another one from the deck instead of playing one at your turn.

- The first player to 15 points wins.

You will need to refer to the next two pages to play this game.

The **Reduced Periodic Table** shows all the elements in the periodic table up to Xenon. These are the elements that can be made with the Atom Building Game. The chart also shows the isotopes that are stable, and the atomic number for each element. This chart is the most important chart to play the game with.

The **Partial Chart of the Nuclides** gives more detail about the elements up to Neon. You can read the numbers of protons and neutrons directly off of the chart, and tell whether the isotopes are stable or not. For the unstable isotopes, the types of instability are shown as well.

Reduced Periodic Table

92, 94-100 — Stable Mass Numbers
Mo — Element Symbol
42 — Atomic Number

1,2 **H** 1																	3,4 **He** 2
6,7 **Li** 3	9 **Be** 4											10,11 **B** 5	12,13 **C** 6	14,15 **N** 7	16-18 **O** 8	19 **F** 9	20-22 **Ne** 10
23 **Na** 11	24-26 **Mg** 12											27 **Al** 13	28-30 **Si** 14	31 **P** 15	32-34, 36 **S** 16	35,37 **Cl** 17	36,38, 40 **Ar** 18
39,41 **K** 19	40,42-44,46, 48 **Ca** 20	45 **Sc** 21	46-50 **Ti** 22	51 **V** 23	50, 52-54 **Cr** 24	55 **Mn** 25	54,56-58 **Fe** 26	59 **Co** 27	58,60-62,64 **Ni** 28	63,65 **Cu** 29	64,66-68,70 **Zn** 30	69,71 **Ga** 31	70,72-74,76 **Ge** 32	75 **As** 33	74,76-78,80, 82 **Se** 34	79,81 **Br** 35	78,80, 82-84, 86 **Kr** 36
85 **Rb** 37	84, 86-88 **Sr** 38	89 **Y** 39	90-92, 94,96 **Zr** 40	93 **Nb** 41	92, 94-100 **Mo** 42	none **Tc** 43	96,98-103,104 **Ru** 44	103 **Rh** 45	102,104-106,108, 110 **Pd** 46	107,109 **Ag** 47	106,108, 110-112, 114,116 **Cd** 48	113 **In** 49	112,114-120,122, 124 **Sn** 50	121 **Sb** 51	120,122, 124-126, 128,130 **Te** 52	127 **I** 53	124,126, 128-132, 134,136 **Xe** 54

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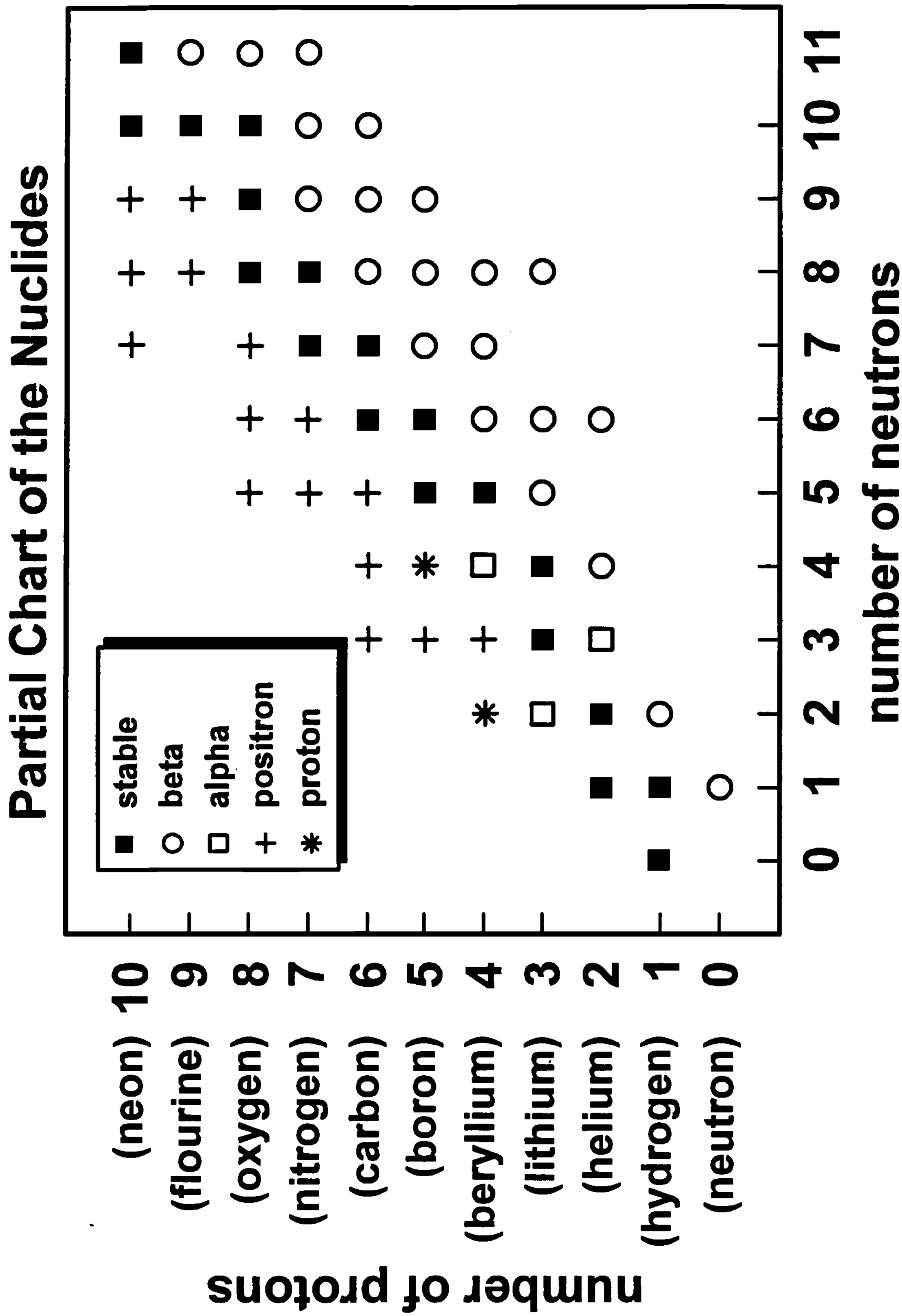


Partial Chart of the Nuclides
stable
beta
alpha
positron
proton
number of neutrons
0 1 2 3 4 5 6 7 8 9 10 11
number of protons
(neon) 10
(flourine) 9
(oxygen) 8
(nitrogen) 7
(carbon) 6
(boron) 5
(beryllium) 4
(lithium) 3
(helium) 2
(hydrogen) 1
(neutron) 0

Name:

PHOTONS AND LASERS

A Stimulating Game of Laser Excitement

AB-G2

This activity is a game for two to five players. To play, we must understand how electrons fill the shells of atoms. In playing, we will see how we can excite atoms, and then trigger them to release the energy that was stored when we excited them.

RULES FOR PHOTONS AND LASERS

- Start with one Atom Building Game board per group, with a full set of marbles and a deck of "Photons and Lasers" cards.
- The board should be set up as neutral neon-20 at the start of the game (10 protons, 10 neutrons, and 10 electrons). The atom should be in the ground state, i.e. all of the electrons should be placed in the lowest layers possible -- this should fill the first and second levels completely.
- Shuffle the cards, and deal each player five cards.
- The players take turns playing cards. When it is your turn:
  - Any card from your hand can be played, i.e. "Pump one" or "Lase three". Take a new card after playing one (you should always have five cards in your hand).
  - When you play a pump card:
    You pump a single electron up.
    The number of levels it is moved up is the same as on the card.
    You declare your move, i.e. "I am pumping an electron from level 1 to level 2".
    You never earn any points for pumping.
  - When you play a lase card:
    You pick one level, and drop *all* electrons from this level the number of levels as on the card.
    The number of electrons that you can drop is limited by the number of electrons on the starting level, and by the number of empty holes on the target level.
    You declare you move, i.e. "I am lasing all electrons from level 3 to level 1".
    You earn points equal to the number of levels dropped x the number of electrons dropped.
  - If you don't like any of your cards, you can trade a card for another one from the deck instead of playing one at your turn.
- The first player to 20 points wins.

Note: if you play a lase card, you only get to drop electrons between two levels. You do *not* get to drop all the electrons on the board. (i.e. playing a "LASE 3" card can drop all the marbles from level 5 to level 2 *or* from level 4 to level 1, but not both). You must also have enough empty holes in the lower levels to accommodate the electrons that you lase.

Let's try an example. Set up the board in ground state neon and play along. In the ground state, there are:

2 in level 1	***8*** in level 2	***0*** in level 3	***0*** in level 4	***0*** in level 5

Player 1 plays a "PUMP 1" card. She decides to move an electron from the second level to the third level. She then draws another card.

Player 2 plays a "PUMP 1" card. He decides to move another electron from the second to third. He then draws another card

Player 3 plays a "PUMP 3" card. He decides to move an electron from the first to the fourth levels. He then draws another card.

Player 4 plays a "PUMP 2" card. She decides to move an electron from the second level to the fourth level. She then draws another card.

The board now looks like this:

1 in level 1	***5*** in level 2	***2*** in level 3	***2*** in level 4	***0*** in level 5

Player 1 now plays a "LASE 2" card. She knows that she can earn the most points by dropping the most marbles. If she drops electrons from level 3 to level 1, she is limited to one electron, because there is only one vacancy at level 1 (even though there are two electrons at level 3). If she drops electrons from level 4 to level 2, she is limited to two electrons, because there are only two electrons at level 4 (even though there are three vacancies at level 2). There are no electrons at level 5 to drop, so she doesn't consider dropping from level 5 to level 3. She decides to drop two electrons from level 4 to level 2, thus scoring 4 points. This leaves the board like so:

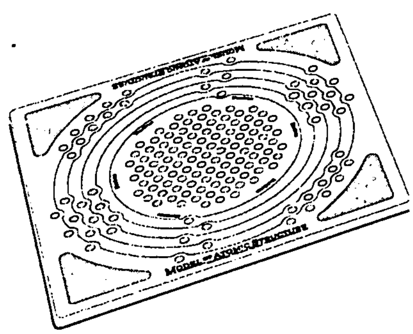
1 in level 1	***7*** in level 2	***2*** in level 3	***0*** in level 4	***0*** in level 5

Player 1 now has 4 points, and the other players have zero. Player 1 draws another card, and the game continues with Player 2.

Name:

Forces in the Atom

AB-B1



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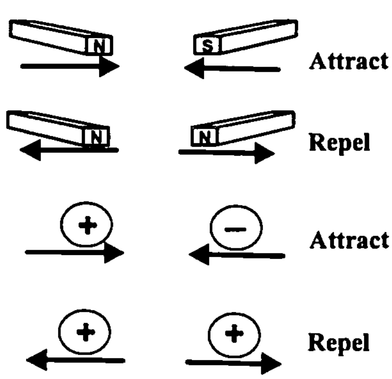
Open up the bags of marbles, and put a few of each type in the corner pockets of the Atom Model.

ELECTRIC FORCES

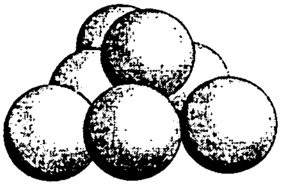


Have you ever experimented with magnets? Electric charges obey similar rules to magnets. If you remember, magnets attract North to South and South to North, but repel North to North and South to South. Electric charges are labeled plus or minus (positive or negative) instead of North and South.

Electric charges obey these rules:

- positive charges repel other positive charges
- negative charges repel other negative charges
- positive charges attract negative charges

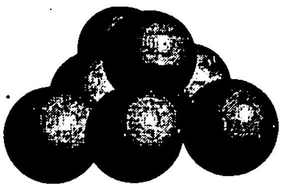
B1.1: Take two protons (red marbles) in your hands. According to the rules of electric forces, should you feel a force? If so, do the protons repel or attract each other?



Protons (red marbles) have positive electric charge

B1.2: Now take two electrons (yellow marbles) in your hands. Do they repel or attract one another?

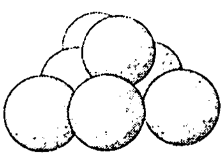
B1.3: Now take two neutrons (blue marbles). Do they repel or attract?



Neutrons (blue marbles) have no electric charge

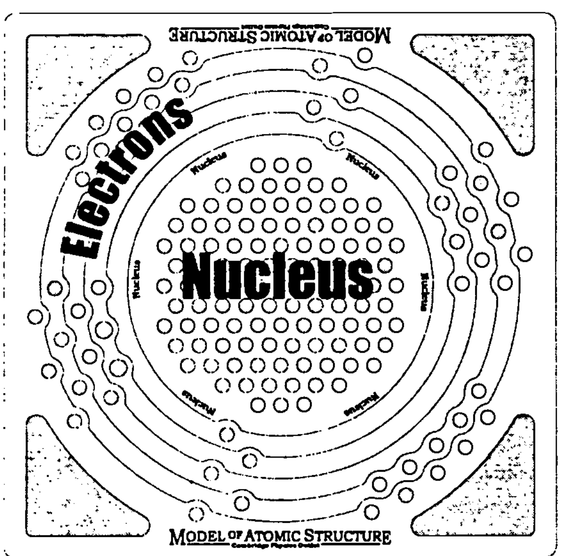
B1.4: How about a proton (red marble) and a neutron (blue marble). Do they repel or attract?

B1.5: How about a neutron and an electron?



Electrons (yellow marbles) have negative electric charge

B1.6: How about a proton and an electron?



Atoms have a nucleus and electrons. Only protons and neutrons live in the nucleus. On the board, this means that only red marbles (protons) and blue marbles (neutrons) go in the center. Electrons are never found in the nucleus.

B1.7: Is the nucleus positively charged or negatively charged?

Nucleus - the core of the atom, containing protons and neutrons

START BUILDING AN ATOM:

Make a nucleus that has three protons in it on the model. Make sure that the marbles go into holes on the model.

B1.8: What is the charge of this nucleus?

____

B1.9: How many electrons should surround this nucleus to make a neutral atom?

____

B1.10: Does the nucleus attract or repel electrons?

____

ADD NEUTRONS TO THE ATOM:

Atoms usually have about the same number of neutrons as protons in the nucleus. Sometimes they have a few more neutrons, sometimes the same number, rarely less.

Continue building your atom with three protons and three electrons.

B1.11: How many neutrons are probably in this atom? Add them.

____

B1.12: What is the charge of the atom now?

____

B1.13: Should the nucleus hold itself together or blow itself apart? Why?

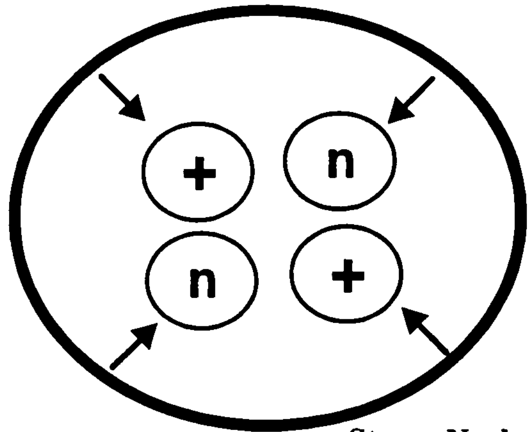
____

____

There is a second force (besides the electromagnetic force) which is necessary to assemble an atom. Scientists call this the **Strong Nuclear Force.** This is an attractive force that holds protons to protons, protons to neutrons, and neutrons to neutrons. It has two main features:

1) It is much stronger than the electromagnetic force (so much stronger that it completely overpowers the repulsion between protons), and

2) It is a very short range force, and nearly disappears outside of the nucleus.



Strong Nuclear Force

Strong Nuclear Force - the short range force that holds the nucleus together

WHERE DO THE ELECTRONS GO?

You know that the nucleus is positive and that electrons are negative. This means that the electrons and the nucleus are attracted to each other. This is how an atom is held together.

Electrons cannot live in the nucleus. Let's figure out where the electrons prefer to go.

Start with your neutral atom of three protons, three neutrons, and three electrons.

B1.14: If the lower levels for the electrons are closer to the nucleus, where do you think the electrons should go? Why?.

___

___

___

Name: ______________________________

Atoms, Isotopes, and Ions

AB-B2

NAMING ATOMS

We label atoms by the number of protons in their nucleus. If two nuclei have the same number of protons, we say that they are the same element, even if the number of neutrons is different. Atoms that have the same number of protons and different numbers of neutrons are different **isotopes** of the same element.

> **Element** - atoms with the same number of protons are of the same element

> **Isotope** - atoms of the same element with different numbers of neutrons are different isotopes of that element

Each element is given a name. These are the names of the first four elements:

Number of protons	Name
1	hydrogen
2	helium
3	lithium
4	beryllium

Right now, we know of 108 different elements. We will learn more about other elements later.

B2.1: Build a neutral atom with three protons and three neutrons. What element is this?

____

B2.2: Where do you think the electrons should go? Why?

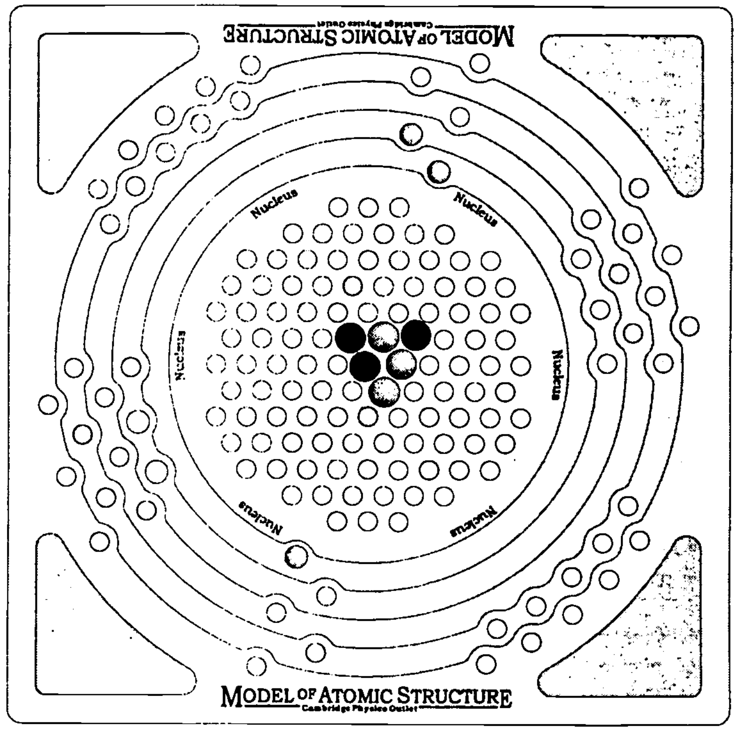
____

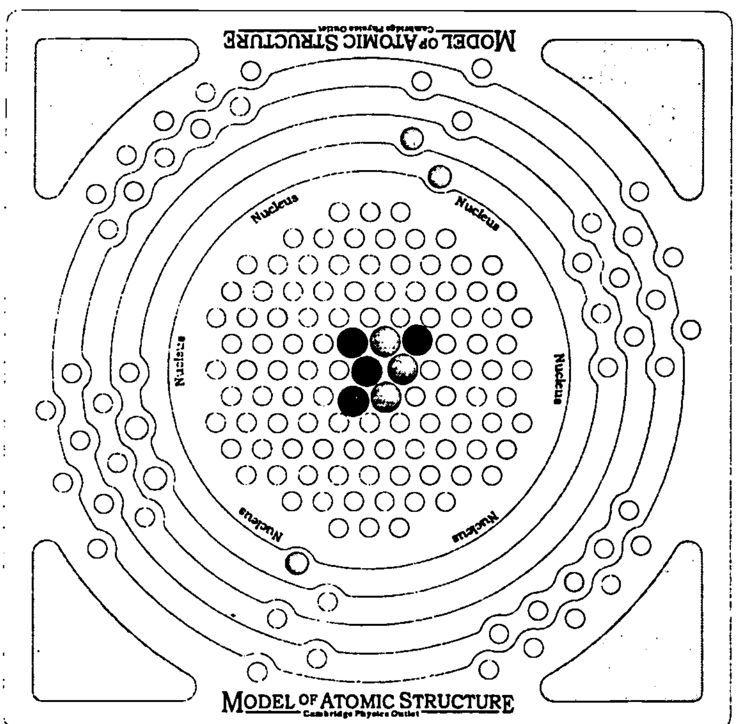
____

B2.3: Now add another neutron to the nucleus? What is the charge on the atom? Is this the same element as before? If not, what element is it?

The number of protons in a nucleus is called the **atomic number** for that element. The number of protons plus the number of neutrons in a nucleus is called the **mass number** for the isotope of that element. We can tell isotopes apart by their mass number. For example, lithium has two isotopes, which are called "lithium-six" and "lithium-seven".

The figure at the right shows lithium-six.





The figure at the left shows lithium-seven.

B2.4: How many neutrons are in lithium-six and lithium-seven?

B2.5: Build a neutral lithium atom (either lithium-six or lithium-seven). Where do you think the electrons should go?

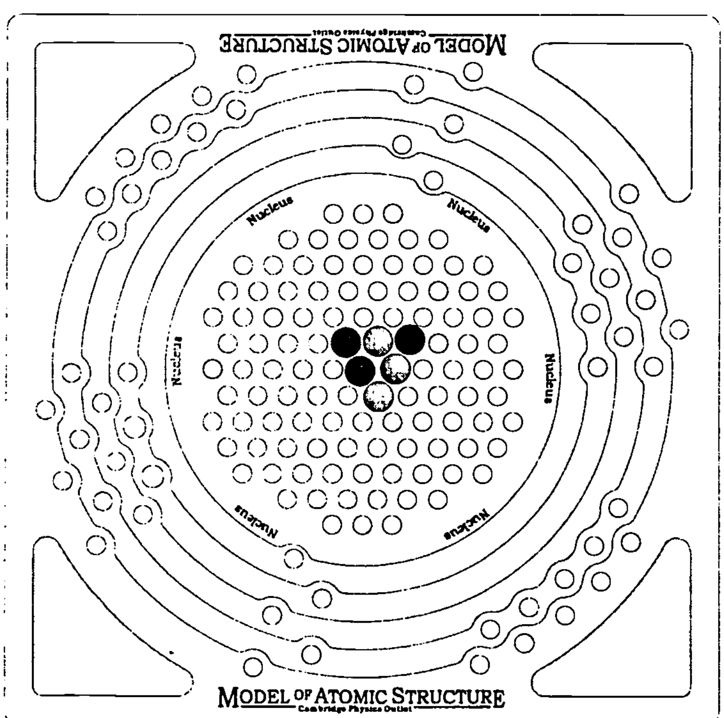
B2.6: Now take away the outermost electron. What is the charge of the atom? What element is it?

ATOMS and IONS

An atom that is not neutral is called an ion. Remember that the element name is determined only by the number of protons. This means that ionizing a neutral atom (adding or taking away electrons) does not change the element -- it only changes the charge.

Ion - an atom that is not neutral (too many or too few electrons)

If an atom has all of its electrons taken away, the atom is **fully ionized.**



The figure at the left shows lithium-six fully ionized.

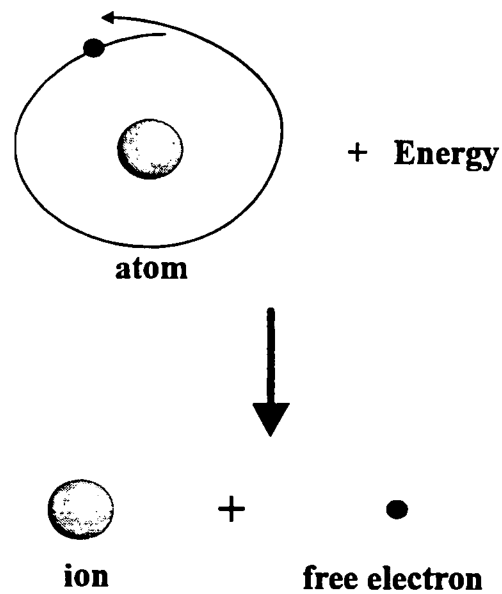
B2.7: What is the charge of a fully ionized lithium ion?

Name: ______________________________

AB-B3

Valence, Chemistry, and the Periodic Table

FAMILIES OF ELEMENTS



We have learned that electrons are attracted to the nucleus. This means that it takes energy to pull electrons away from the atom.

One experiment that scientists like you can do (with the right equipment) is to measure the energy that it takes to pull one electron from a neutral atom.

B3.1: Build neutral neon (ten protons, ten neutrons, ten electrons). Now ionize it by removing one electron. Where did you remove the electron from?

____

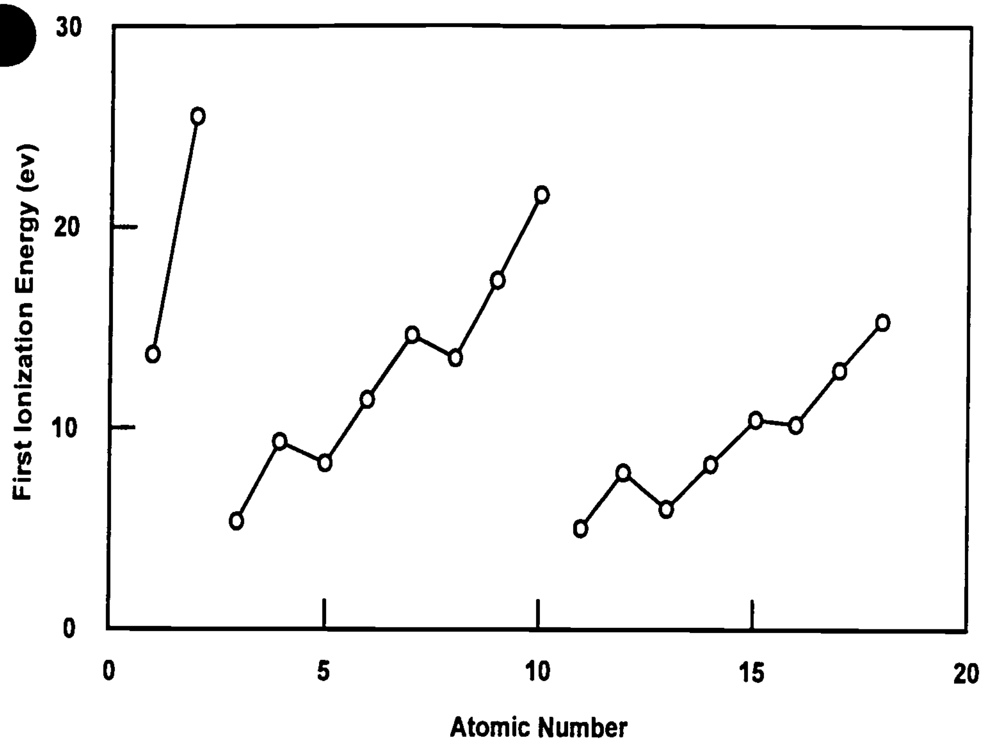
B3.2: Build neutral sodium (eleven protons, twelve neutrons, eleven electrons). Now ionize it by removing one electron. Where did you remove the electron from?

____

B3.3: Do you think it takes more energy to ionize neon or sodium? Why?

____

____



The graph at the left shows the first ionization energy for each of the elements up to atomic number 18. (This is called the **first** ionization energy, since it is the energy required to remove the first electron from the neutral atom).

B3.4: From this graph, find the ionization energies for neon and sodium. Were you right in question **B3.3?**

B3.5: What are the units of energy shown in the graph? What were the units of energy that you have used before (such as in the Rollercoaster experiment)?

B3.6: Can you guess why it isn't convenient to use the same units of energy for both experiments?

B3.7: Fill in the table below by building the atoms on the board to find the levels for the outermost electrons. You will have to refer to the graph above for the ionization energy.

Element	outermost level with an electron	total number of spaces in this level	total number of spaces filled in this level	1st ionization energy (eV)
hydrogen	*1*		*1*	
helium		*2*		
lithium				*5.4*
beryllium	*2*		*2*	
neon		*8*	*8*	*21.6*
sodium	*3*			

B3.8: From this table and from the graph of ionization energy, we can look for patterns in ionization energy. Do you think that the ionization energy is about the same for all elements with the outermost electron at the same level?

____

B3.9: Do you think that the ionization energy increases as the number of electrons increases?

____

B3.10: Do you think that the ionization energy increases as the outermost level becomes more filled?

____

B3.11: Based on what you have learned, which element is lithium most like: helium, beryllium, or sodium?

____

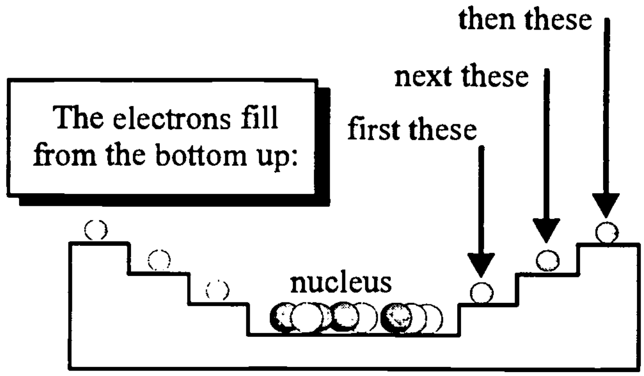
B3.12: Similarly, which element is neon most like: helium, beryllium, or sodium?

____

VALENCE AND CHEMISTRY

Let's recap what we have learned.

- A neutral atom has the same number of electrons as protons.
- Electrons don't live in the nucleus, only in the levels surrounding the nucleus.
- Since electrons are attracted to the nucleus, electrons fill the lowest (closest) levels first.
- Electrons must go into a hole. Once a given level is full, electrons have to start filling the next level.



We also found that there are patterns that occur in the energy necessary to ionize an atom. Do similar patterns exist elsewhere?

Yes! Chemists have long known that many elements behave very much the same. For example, lithium, sodium, and potassium are so similar that it can often be difficult to distinguish them. Similarly, chlorine, fluorine, and bromine are very similar.

B3.13: Build the following elements, and list the number of electrons and the number of remaining holes in the outermost level that is at least partially filled.

Element	Atomic Number	Electrons in Last Level	Holes in Last Level
hydrogen	1		
helium	2		
lithium	3		
fluorine	9		
neon	10		
sodium	11		
chlorine	17		
argon	18		
potassium.	19		

B3.14: What do helium, neon, and argon have in common in this table?

____

B3.15: What do lithium, sodium, and potassium have in common in this table?

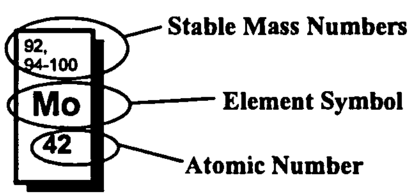
____

The number of electrons in the last level of an atom is called its **valence.** Lithium, sodium, and potassium all have a valence of +1. Valence is sometimes given as a negative number, referring to the number of holes left in the last level. Fluorine and chlorine both have a valence of -1.

PERIODIC TABLE

Chemists have long noticed that some groups of elements behave similarly (long before electron levels were understood, in fact). The periodic table is an arrangement of the elements in such a way as to group together these elements that behave the same. A reduced periodic table (i.e. only those elements that we can construct with the Atom Building Game) is shown below.

Reduced Periodic Table



1,2 H 1																	3,4 He 2
6,7 Li 3	9 Be 4											10,11 B 5	12,13 C 6	14,15 N 7	16-18 O 8	19 F 9	20-22 Ne 10
23 Na 11	24-26 Mg 12											27 Al 13	28-30 Si 14	31 P 15	32-34, 36 S 16	35,37 Cl 17	36,38, 40 Ar 18
39,41 K 19	40,42-44,46, 48 Ca 20	45 Sc 21	46-50 Ti 22	51 V 23	50, 52-54 Cr 24	55 Mn 25	54,56-58 Fe 26	59 Co 27	58,60-62,64 Ni 28	63,65 Cu 29	64,66-68,70 Zn 30	69,71 Ga 31	70,72-74,76 Ge 32	75 As 33	74,76-78,80, 82 Se 34	79,81 Br 35	78,80, 82-84, 86 Kr 36
85 Rb 37	84, 86-88 Sr 38	89 Y 39	90-92, 94,96 Zr 40	93 Nb 41	92, 94-100 Mo 42	none Tc 43	96,98-103,104 Ru 44	103 Rh 45	102,104-106,108, 110 Pd 46	107,109 Ag 47	106,108, 110-112, 114,116 Cd 48	113 In 49	112,114-120,122, 124 Sn 50	121 Sb 51	120,122, 124-126, 128,130 Te 52	127 I 53	124,126, 128-132, 134,136 Xe 54

Look at the column on the left of the Periodic Table. The elements H, Li, Na, K, and Rb all have a valence of +1. These are called the Group 1 elements. The elements He, Ne, Ar, Kr, and Xe all have a valence of 0 (this is because there are no holes left - the outermost shells are all full).

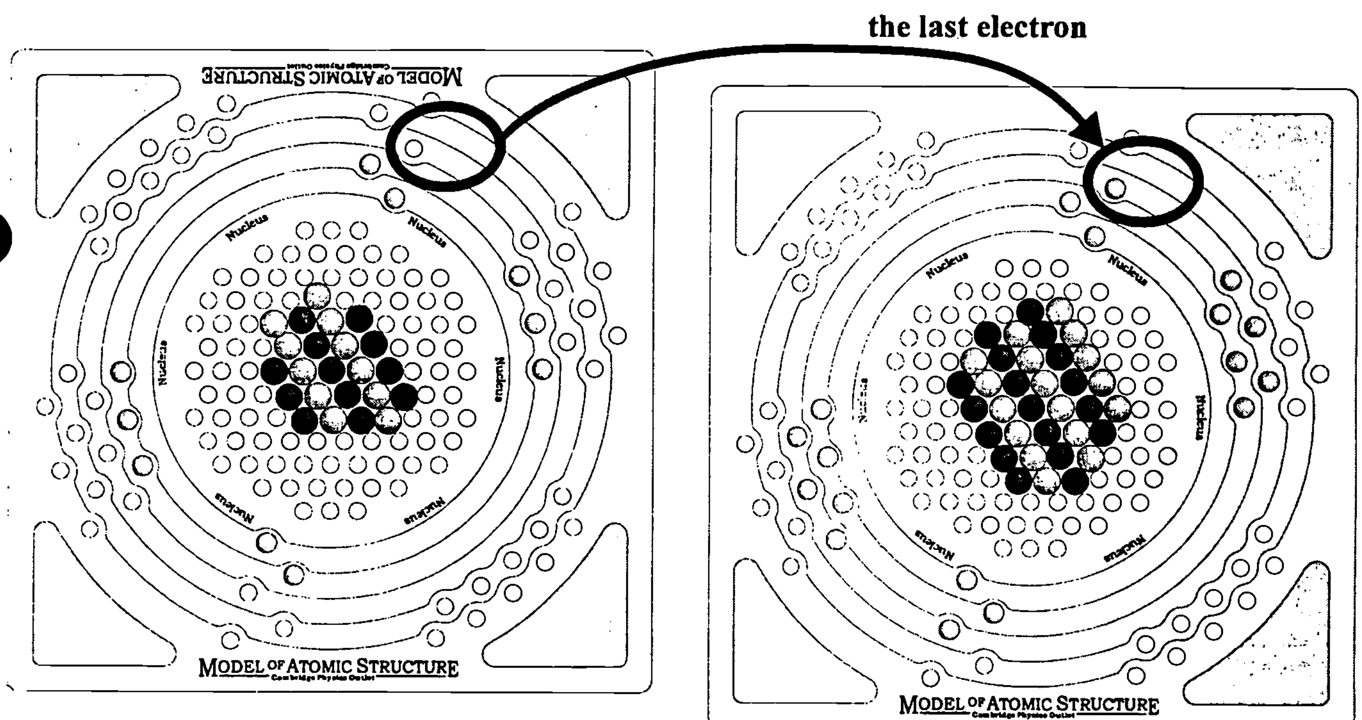
VALENCE AND CHEMICAL BONDS

You can think of the first ionization energy of an atom as a measure for how tightly the atom is holding on to all of its electrons. Noble gases such as helium, neon, and argon have a full outermost level. We see that noble gases have the highest first ionization energies of any group, which means that they want to keep all of their electrons. In other words, noble gases want to keep their last levels full.

Group 1 elements, such as hydrogen, lithium, and sodium, have one more electron than a full level. Of all the groups, group 1 elements all have the lowest first ionization energies. This means that group 1 elements readily give up their last electron. Once they give up their last electron, they have only full levels remaining.

Two or more atoms can share electrons so that each of them has full electron levels. This is called **bonding.** Atoms which bond together form a **molecule.** One common example of this is table salt, which is a bond between sodium and chlorine. Bonds between elements can be formed or broken, but a bond does not change elements themselves.

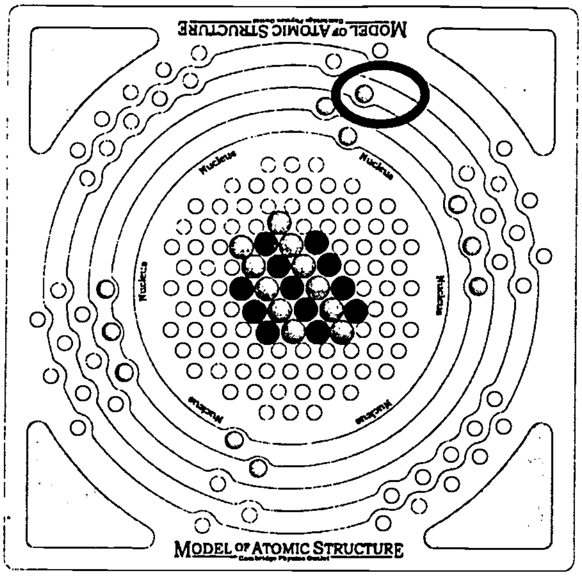
Using two Atom Building Games, build a neutral sodium atom on one board and a neutral chlorine atom on the other. Put the boards side by side.



Sodium Atom

Chlorine Atom

B3.16: Describe how these two atoms bond together to form a molecule. Is the molecule neutral?

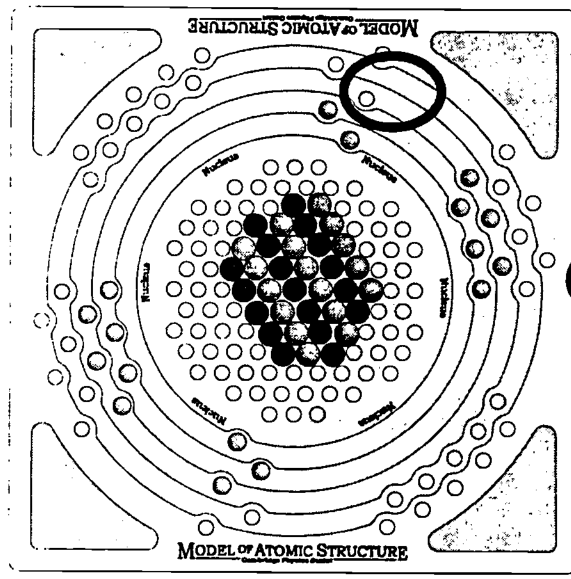


B3.17: Here is a neutral sodium atom. What is the charge on the atom? How full is the outermost shell of electrons?

B3.18: Look at the sodium atom in the salt molecule. What is the charge on the atom? How full is the outermost shell of electrons?

B3.19: Here is a neutral chlorine atom. What is the charge on the atom? How full is the outermost shell of electrons?

B3.20: Look at the chlorine atom in the salt molecule. What is the charge on the atom? How full is the outermost shell of electrons?



B3.21: What other element might form the same kind of bond with sodium? Explain why?

B3.22: Build a neutral argon atom (atomic number 18). What elements might easily bond with argon? Why?

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